FLOW BASED MARKET COUPLING

DEVELOPMENT OF THE MARKET AND GRID SITUATION 2015 - 2017

amprion

CONTENTS

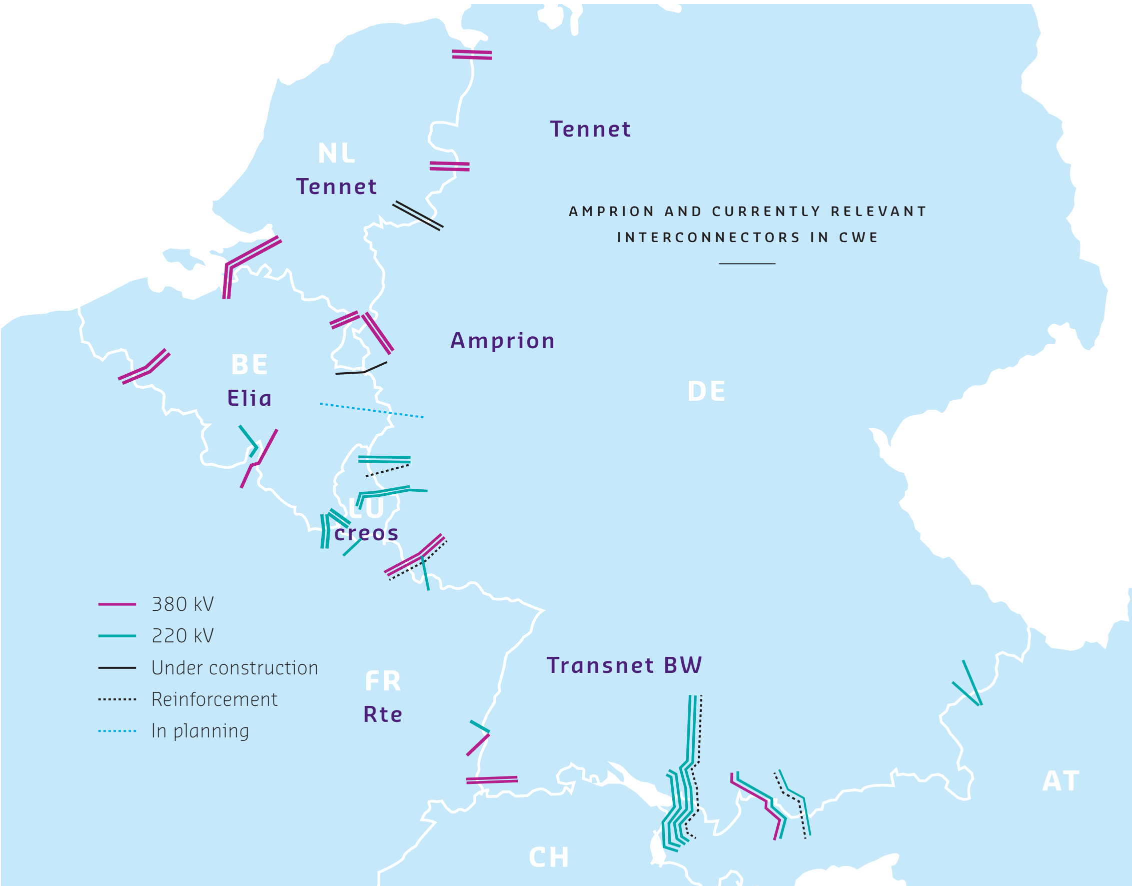
Flow based market coupling – Development of the market and grid situation

Executive Summary

In the current debate on the further development of the Flow based market coupling (FBMC) the most prominent criticism is the alleged limitation of cross-zonal exchanges by TSOs. This is supposed to be due to insufficient coordination amongst TSOs and, more importantly, the discrimination of cross-zonal exchanges in favor of internal exchanges.

Regrettably, the significant progress of market integration over the last years as well as the strong mutual support between TSOs during critical electricity grid and supply situations rarely gets mentioned in this context.

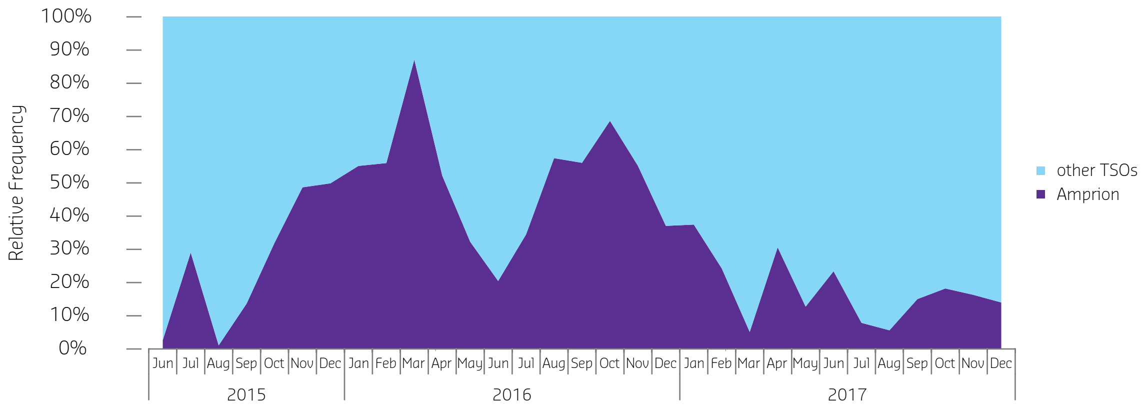
Right from the very beginning of market integration, Amprion has together with its neighboring TSOs been actively participating in a large number of regional and European initiatives, including the CWE, NWE, MRC and CORE market coupling as well as the XBID, TSC, SSC and IGCC projects[1]. This report provides evidence for the significant mutual benefits resulting from our strong and steadily enhanced cooperation with TSOs of the CWE region and beyond.



1) Market coupling projects: Central Western Europe (CWE), North Western Europe (NWE), Multi Regional Coupling (MRC), CORE (CWE + CEE) and Cross Border Intraday (XBID). Security cooperations: Transmission System Operator Security Cooperation (TSC), Security Service Centre (SSC). Balancing projects: International Grid Control Cooperation (IGCC).

In more concrete terms:

- German exports towards its neighbours regularly reach absolute levels of up to 15 Gigawatts, ensuring security of supply in those regions, in particular during electricity shortage situations.
- Capacities provided to the market in the CWE region remain at constant high levels.
- Average price convergence within the CWE regions shows a steadily increasing pattern, providing evidence for a continuously increasing market integration.
- In response to critical supply situations in neighbouring countries during 2016, Amprion has improved the capacity calculation to accommodate further electricity exports. Due to the central location of the Amprion control zone within the CWE region, the market situation becomes very transparent. This transparency has given indications of major bottlenecks in the region which have been effectively resolved by Amprion. As a result, the frequency of Amprion's network elements constraining the market has reduced substantially.



Relative frequency of top 10 active CBs per hour of the day from 06.2015 – 12.2017
(Amprion without Amprion's cross-border lines DE/AT/LU-NL)

Furthermore, the critical electricity supply situation in 2016 needs to be put into perspective of market influences which are not exclusively driven by the transmission grid and related transaction constraints, i.e. flow based parameters. Other further fundamental factors have also been impacting the market to a significant extent. On the one hand, considerable changes in the generation mix, i.e. decommissioning and unavailability of conventional generation units, have led to a shift of generation centers in CWE countries. On the other hand, import needs are strongly driven by the infeed from variable renewable energy sources and the electricity demand, which in turn are heavily impacted by the natural variability of climate and weather conditions.

Against this background, this report provides a more profound analysis of the historical developments within the CWE FBMC. The focus of the report is on capacity calculation and market coupling as well as on the grid situation and developments of the generation pattern within the CWE region.

Capacity calculation improvements
Improvements with regard to capacity calculation inputs, e.g. introduction of higher seasonal maximum allowable power flows (Fmax) and dynamic line rating, have led to an increase of the capacity provided to the market. Furthermore, the lowest FRM-values can be observed for Amprion with only 8.8 % on average which in turn leads to comparatively higher capacities made available to the market. Nevertheless, capacity calculation inputs, i.e. conventional generation, wind generation and electrical load, are subject to considerable seasonal patterns affecting the feasibility of cross-border exchanges. Besides wind generation the highest relationships are observed between exchange capabilities and local scarcities of conventional generation units in CWE countries.

Low and decreasing levels of conventional generation
Conventional generation within the region is already at insufficient levels to ensure self-sustainability in some countries and/or shows a decreasing trend. This leads to situations where countries are reliant on each other and hence are requesting higher export capacities within the region.

Market Coupling leads to high exports from Germany
Exports from Germany into the CWE region remain at high levels and the number of hours with limiting German internal critical branches has decreased significantly in 2017. There is a correlation between Amprion critical branches and price spreads between DE-FR, DE-BE and DE-NL, which decreased over time. Consequently, price spreads in CWE are increasingly determined by other constraints, mainly in the Netherlands and Belgium. At the same time a decrease of loop flows via Belgium is observed.
Moreover, a considerable shift of exports from northern CWE borders to southern borders takes place. This higher demand for imports into the south of CWE is caused by generation scarcities in some countries.

A more constrained grid situation
These high transit flows from North to South are a result of increased export flows from Belgium and Germany to France. Net Exports from the Amprion control zone to neighbouring control zones exceeded 12 GW, which has ensured security of supply in the CWE region during the winter period 2016/17. The facilitation of these increased North-South transits in the CWE region has led to considerably higher redispatch volumes, in particular for Amprion, which reached a historical height during that period. This shows our strong commitment to the European market integration and the support we provide to our neighbors, while accepting significant redispatch costs for ourselves.

In summary, the overall measures taken by TSOs over the past years have provided very effective support of cross-border trading and security of supply in neighbouring countries.

This study provides evidence for the effective support by first giving a general overview on flow based capacity calculation in chapter 1. This overview represents the general framework for the following sections where in chapter 2 inputs to the capacity calculation and the respective improvements are analyzed. Section 3 discusses the capacity calculation outputs which are used in the market coupling which is subject of chapter 4. Section 5 concludes the report with a discussion of system operation and in particular redispatch activities taken by Amprion to accommodate significant cross-border exchanges in particular during the winter period 2016/17.

1. Flow Based Capacity Calculation and Allocation

In general in a zonal electricity market, the determination of the available capacity between bidding zones requires a translation of physical transmission constraints into commercial transaction constraints (see Figure 1: Capacity calculation inputs and outputs). These simplified commercial transaction constraints are then considered in the market clearing algorithm determining market prices and cross-border exchanges between participating bidding zones (Market coupling). Occurring congestions require redispatching measures, which are coordinated by affected TSOs during real-time grid operation (Grid operation). The following figure gives an overview over relevant inputs and outputs of the flow based capacity calculation and allocation as well as grid operation.

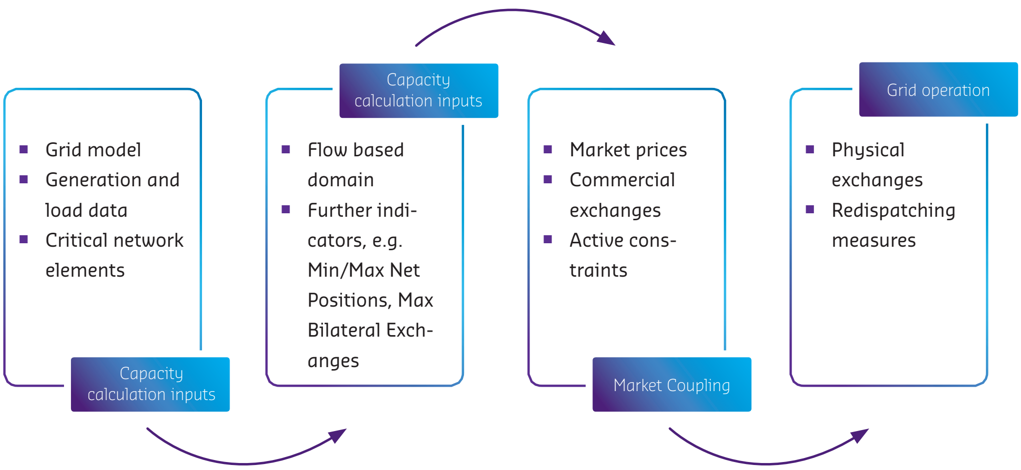


Figure 1: Overview over flow based capacity calculation and allocation

The main enhancement of the flow based market coupling against the NTC[2]-based market coupling is the (direct) consideration of physical transmission constraints in the market clearing algorithm. Accordingly, all critical network elements relevant for cross-border exchange are taken into account in the market clearing bringing commercial transactions closer to the physical reality.
The impact of commercial transactions, i.e. change of Net Positions, on flows through critical network elements is considered by zonal Power Transfer Distribution Factors (PTDFs). The flows through critical network elements are limited by the Remaining Available Margin (RAM), which is derived from technical parameters and the system state within the flow based capacity calculation process.
Both parameters define the flow based domain representing all feasible combinations of commercial exchanges between participating bidding zones. Hence, in contrast to the NTC-based approach, commercial exchanges between two bidding zones are dependent on feasible commercial exchanges between other bidding zones.
Due to the better representation of the physical characteristics of the transmission grid, i.e. Kirchhoff's laws, a less conservative determination of the flow based parameters is possible. This leads in most cases to a larger flow based domain and higher welfare gains than under the NTC-based approach.

In the following sections the focus is on the steps of the flow based capacity calculation and allocation process as depicted in Figure 1. In each section relevant parameters and indicators are analysed in order to evaluate the development over the past years.

[2] Net Transfer Capacity

2. Capacity Calculation Inputs

To calculate flow based capacities, TSOs have to prepare several inputs used in the capacity calculation process. Basically, TSOs consider best estimates of the state of the CWE electric system containing forecasts with regard to grid topology, generation and load.
Moreover, TSOs have to determine parameters for the relevant critical network elements, i.e. maximum current on a critical network element (Imax) and Flow Reliability Margins (FRM). In order to map changes in net positions to the generating units in a bidding zone, Generation Shift Keys (GSK) are defined. To ensure secure power system operation, TSOs take into account remedial actions during capacity calculation, e.g. changing the tap position of a phase shifter transformer or topological measures[3].
Besides the definition and determination of the above mentioned parameters generation and load patterns can have considerable impacts on the system state also determining the resulting constraints and exchange capabilities taken into account in the market clearing algorithm.Subsequently we review the development of the most relevant parameters as well as of the generation and load situation in the CWE region.

HIGHER MAXIMUM ALLOWABLE POWER FLOW (FMAX)

The capacities given to the market are amongst other parameters determined by the maximum allowable power flow on a critical network element (Fmax) as an input parameter for the flow based capacity calculation process. In order to support cross-border trade and as part of continuous improvements of the FBMC, CWE TSOs introduced seasonal Fmax-values. Some TSOs moreover implemented dynamic line rating leading to higher capacities in particular during cold periods with a higher electricity demand. Accordingly, import and export capabilities have been increased in particular during the winter period with a higher power demand and corresponding higher socio-economic value.

The maximum allowable power flow on a critical network element (Fmax) is derived from the maximum current on a critical network element (Imax). Imax is the physical (thermal) limit of the critical network element, which depends on the weather conditions and is usually fixed at least per season. Further to the physical limits of the network element itself, other relevant limitations need to be acknowledged. Such limitations include in particular maximum allowable voltage inductions into parallel infrastructure, e.g. gas pipelines which must not exceed certain threshold values. Otherwise, a safe and secure operation of the infrastructure ensuring in particular human safety is no longer guaranteed.

After go live of the flow based market coupling in 2015 CWE TSOs have focused on developing a regional process to coordinate remedial actions, in particular for the coordination of phase shifting transformers and topological measures. Consequently in order to maintain secure grid operation, TSOs considered seasonal Fmax-values only on selected critical network elements during the winter period 2015/16, i.e. transmission lines Diele-Meeden, Siersdorf-Maasbracht or Mercator-Brode.

[3] For further details see "Documentation of the CWE FB MC solution" at http://www.jao.eu.

After implementation of the process for coordinated remedial actions and the subsequent elimination of Final Adjustment Values (FAV)[4] on critical network elements, Amprion introduced seasonal Fmax-values on further lines for the winter period 2016/17. Accordingly, thermal limits have been increased by up to 20 % (≈400 MW).
In 2017 CWE TSOs continued the development. Amprion, for example, introduced a dynamic line rating approach on its transmission lines allowing adaptive Fmax-values as a function of weather conditions, i.e. temperature. By this means thermal limits can be increased by more than 20 % in particular during cold weather conditions usually associated with a high electricity demand.

LOW FLOW RELIABILITY MARGINS (FRM) SUPPORT HIGHER CAPACITIES

In order to cope with uncertainties, i.e. deviations from forecasts, between the points in time of the capacity calculation and real-time operation TSOs apply reliability margins for the considered critical network elements. The so-called Flow Reliability Margin (FRM) is deducted from the corresponding Fmax-value and accordingly reduces the thermal limit considered in the capacity calculation process. FRM-values are in the range between 5 and 20 % of the respective Fmax-value. The lowest FRM-values can be observed for Amprion with only 8.8 % on average which in turn leads to comparatively higher capacities made available to the market.

Considering FRM-values on all active critical network elements the limitation of the maximum allowable power flow (Fmax) due to uncertainties ranges between 66 and 357 MW (183 MW or 13 % of Fmax on average) in the CWE region (see Figure 2).
In contrast, Amprion applied FRM-values much lower than the average right from the beginning of the FBMC in 2015. As shown in Figure 2, FRM-values on active critical network elements of Amprion amount to only 155 MW or 8.8 % of Fmax on average. Accordingly, the restriction of cross-border trade due to uncertainties is rather limited for critical network elements of Amprion (Fmax-values range between 69 and 256 MW).

[4] FAV can be used by TSOs to reduce or increase remaining available margin (RAM) on a critical network element for very specific reasons, i.e. system security reasons.

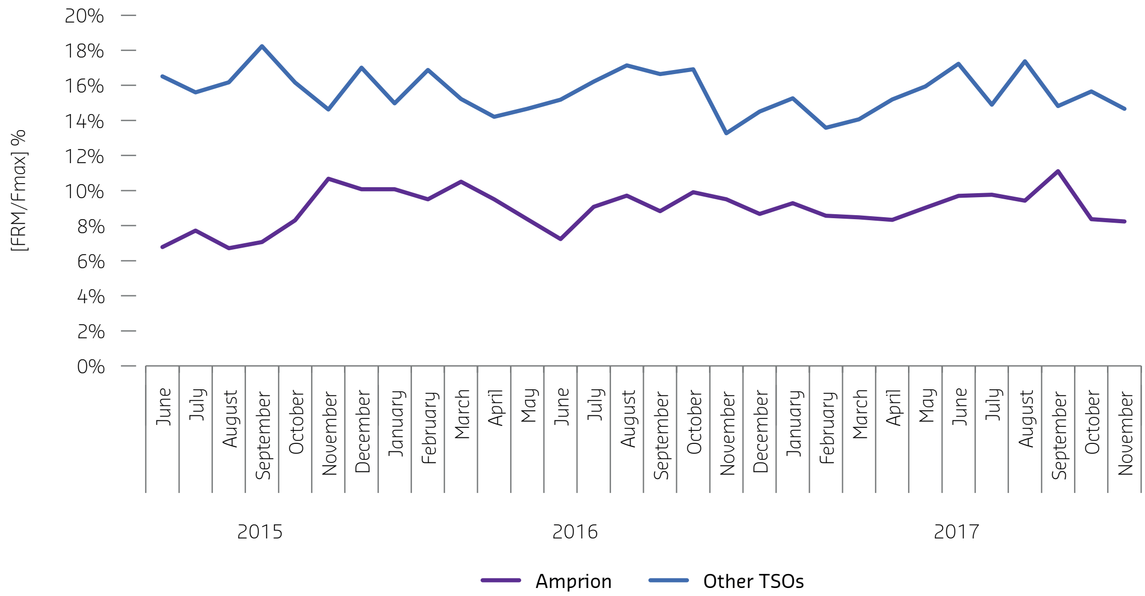


Figure 2: Monthly average FRM-values of active constraints in CWE

According to a recalculation of FRM-values in the course of study performed by CWE TSOs in 2016, uncertainties and corresponding FRM-values increased since the go live of the CWE FBMC. However, in order to not limit cross-border trade, CWE TSOs decided to not increase FRM-values meaning that TSOs take the risk.

DECREASING LEVELS OF CONVENTIONAL GENERATION IN THE REGION

While electricity demand stayed relatively stable, conventional generation capacities have decreased in all CWE countries in recent years. In combination with a historically high unavailability of generation facilities high national and local supply scarcities can be identified, driving the price level on the electricity markets and leading to steadily increasing requests for cross zonal capacity.

In **Germany** the nuclear phase out already led to a shutdown of about 2 GW generation capacities since 2015. Moreover, old coal units and unprofitable gas plants have been decommissioned in recent years, leading to an overall reduction of conventional generation capacity by 5,1 GW. Installed firm capacity remains at about 116 GW which is sufficient to cover the national peak load of 83 GW[5].

[5] See national adequacy report: https://www.netztransparenz.de/portals/1/Content/ Ver%c3%b6ffentlichungen/Bericht_zur_Leistungsbilanz_2017.pdf

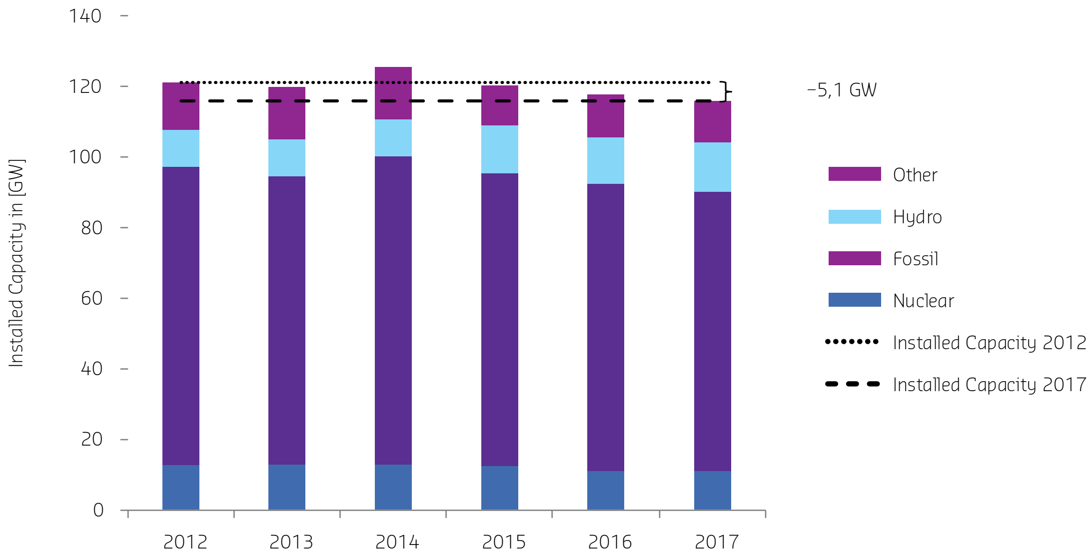


Figure 3: Development of installed generation capacity in Germany (without wind & solar), Source: BMWi, Entso-E

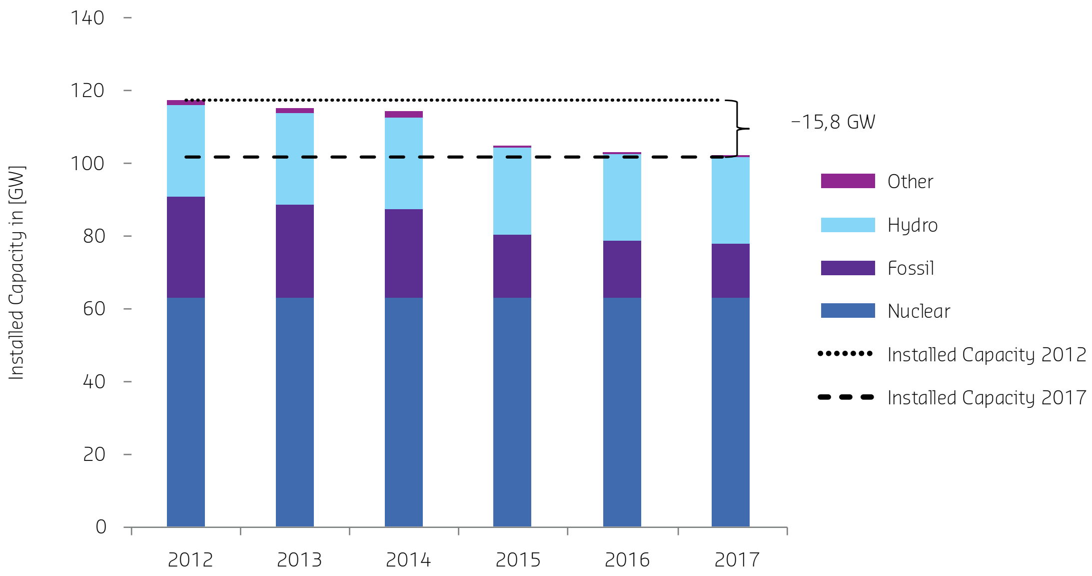


Figure 4: Development of installed generation capacity in France (without wind & solar), Source: RTE, Entso-E

In **France** the electricity demand is supplied by nuclear generation units to a large extent. While the installed generation capacity of nuclear remained unchanged a considerable amount of fossil units (coal and gas) has been shut down over the past years. Overall a reduction of about 15 GW of conventional generation capacity is observed between 2012 and 2017. Installed conventional generation capacity remains at about 102 GW at the end of 2017. According to the national adequacy report the national peak load is likely to exceed 95 GW (in 30 % of the cases), making France dependent on a reliable generation fleet and imports from neighbouring countries[6].

For **Belgium** no considerable decrease of conventional generation capacities is found. Installed firm capacity remains at about 15 GW which is, however, insufficient for a self-sustainable electricity supply. Under consideration of (planned and unplanned) unavailabilities of generation units, the national peak demand of up to 14.5 GW (2010) is likely to exceed the available generation capacity, making Belgium reliant on imports during periods of high electricity demand[7].

In the **Netherlands** installed capacities mainly of hard coal decreased in recent years, leading to shutdown of about 4 GW. Installed firm capacity remains at about 25.5 GW with a national peak load of about 18 GW[8].

For the near future the decrease of conventional generation capacities is expected to continue in all CWE countries, further increasing local scarcities and changing capacity calculation inputs[9].

In the short term the supply side is moreover characterized by unavailibilities of generation units due to maintenance (planned outage) or technical failures (unplanned outage). Accordingly, unexpected unavailabilities can induce considerable scarcities, as happened during the winter period 2016/2017. In particular more than 20 GW of conventional base load capacities in southern CWE countries was not available for the market in the CWE region during that critical period, which led to considerable changes in generation patterns.
In this regard it has to be noted that in contrast to the ongoing debate on cross-border transmission capacities, large supply gaps can be merely solved by higher imports.

6) See national adequacy outlook: http://www.rte-france.com/sites/default/files/bp2016_complet_vf.pdf

7) See national adequacy report: http://www.elia.be/~/media/files/Elia/Products-and-services/Strategic-Reserve/20161201_Adequacy-Study_EN_2017-2018.pdf

8) See national adequacy report: https://www.tennet.eu/fileadmin/user_upload/Company/ Publications/Technical_Publications/Dutch/Rapport_Monitoring_Leveringszekerheid_2017_web.pdf

9) See Second Report on Generation Adequacy Assessment within PLEF Region: https://www.amprion.net/Dokumente/Dialog/Downloads/Studien/PLEF/2018-01-31-2nd-PLEF-GAA-report.pdf

WIND GENERATION

Besides conventional generation, capacity calculation and allocation are moreover affected by the infeed of variable renewable energy sources. In particular wind generation in Germany is considered to be a main driver of transmission capacities and cross-border exchanges.

Between 2014 and 2017 wind capacities increased from 39.2 GW to more than 55 GW (+40 %) in Germany. Despite the considerable increase of generation capacities, the wind infeed however remained nearly constant between 2015 and 2016 (79.2 TWh and 78.6 TWh). This is mainly due to lower wind yields in 2016 counterbalancing the additional installed capacities.In contrast, wind generation reached more than 100 TWh in 2017. In particular in Q4 2017 the German wind infeed was about 60 % higher against the same period in 2016 (37.7 TWh compared to 23.3 TWh). Moreover, the variability of the wind infeed increased by more than 25 % between 2015 and 2017 leading to higher uncertainties in the capacity calculation process.

According to the approved flow based capacity calculation methodology TSOs shall consider the best forecasts with regard to generation and load patterns. The increasing share of variable renewable energy sources adds uncertainty to power system operation and capacity calculation. Besides impacts on reliability margins the high concentration of wind generation in North Germany leads to increasing volatility of the overall wind infeed and to considerable increases of the utilization of the existing transmission infrastructure.
In addition to best estimates of exchange programs, outages of transmission lines, production and unavailabilities of generation facilities, and load patterns TSOs consider best estimates of the infeed from wind and solar power for the generation of congestion forecasts (D2CF and DACF) as input for the capacity calculation process.
As already considered by the so-called C-Function[10], the German wind infeed has a considerable impact on cross-border capacities to the Netherlands, France and Switzerland, i.e. decreasing cross-border capacities with increasing wind infeed. Moreover, academic studies find wind generation and its natural variability to be a main driver of redispatching measures[11] (see also section 5).

Against this background it should be noted that there are fundamental factors like variable renewables infeed affecting capacity calculation and market coupling in a way, which is out of TSOs control.

10) See "Approved capacity calculation scheme", available at: https://www.amprion.net/Dokumente/ Strommarkt/Engpassmanagement/Kapazitätsmodelle/150520_capacity_calculation_scheme_amprion.pdf

11) See e.g. Wohland et. al (2018)

As the following Figure reveals wind capacities increased from 39.2 GW to more than 55 GW (+40 %) in Germany between 2014 and 2017. At the same time the annual wind infeed however decreased between 2015 and 2016 due to lower wind yields (from 79.2 to 78.6 TWh). In contrast wind generation reached more than 100 TWh in 2017. Accordingly, when analyzing exchange capacities, market coupling results and the grid situation such considerable changes in the system conditions should be reflected.

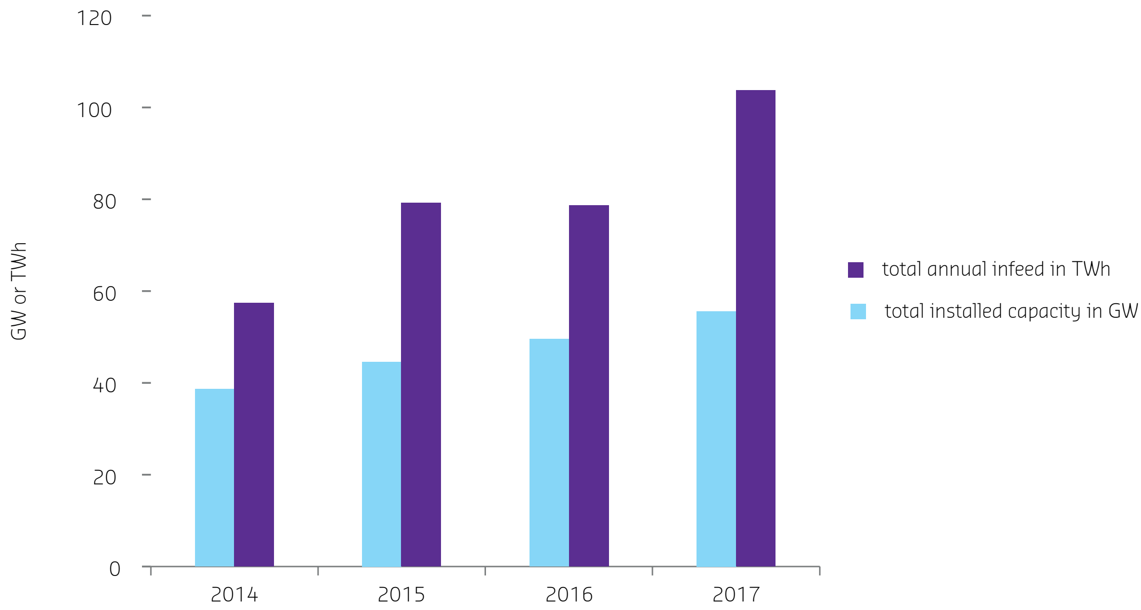


Figure 5: Installed wind capacity and wind generation (Germany)

Moreover, the variability of the wind infeed increased by more than 25 % between 2015 and 2017 leading to higher uncertainties in the capacity calculation process (increase of the standard deviation of the wind infeed from 6985 MW to 8811 MW).

3. Capacity Calculation Outputs

The main output of the capacity calculation process is the Flow based domain, which can be characterized by indicators as described in this section. As such, the Flow based parameters determine the transaction constraints considered in the market coupling algorithm. This means the parameters indicate all feasible net positions under consideration of the critical network elements and without endangering the grid security.

The Flow based domain can be analysed by computing its volume, which is spanned by all binding constraints, i.e. critical network elements. Moreover, maximum and minimum net positions for each hub and bilateral exchanges between any two hubs, feasible within the Flow based domain can be computed.

INCREASING VOLUME OF FLOW BASED DOMAIN

The volume of the flow based domain indicates the size of the solution space for the market coupling, which is spanned by relevant constraints. Overall an increasing trend of the flow based volume can be observed, meaning that capacities for cross-border trade increased over the past years.
It should be noted that this indicator considers all possible directions for exchanges, not only the most relevant and likely market directions. Further insights into the development of constraints for cross-border trading are given in the following.

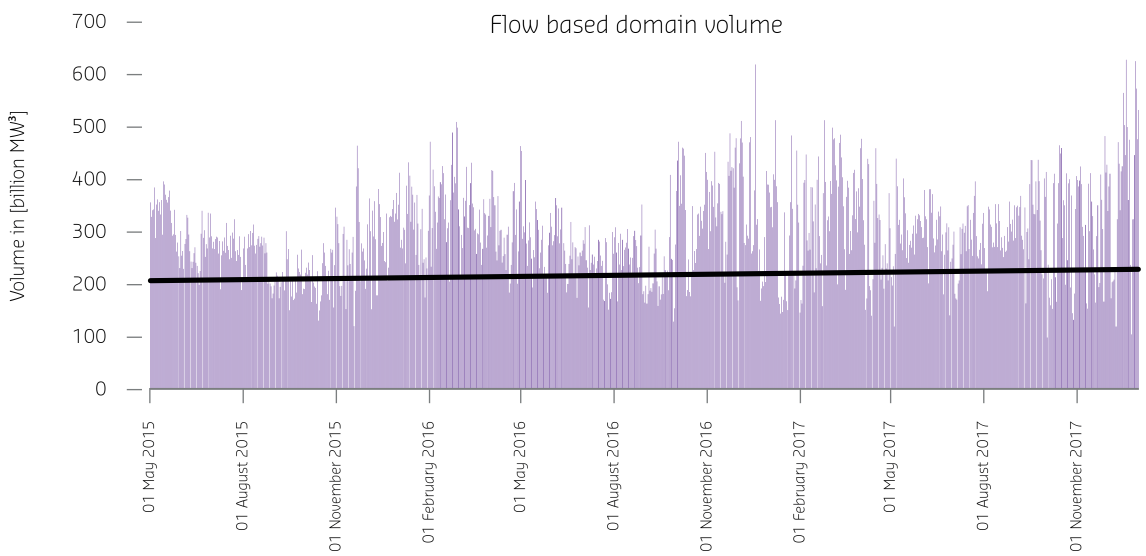


Figure 6: Volume of the flow based domain in billion MW³

CONSTANTLY HIGH MAXIMUM AND MINIMUM NET POSITIONS

Maximum (export) and minimum (import) net positions are extracted from the vertices of the final flow based domain given to the market coupling[12].

The extracted net positions are subject to seasonal patterns. In particular import capabilities of France and Belgium have remained at a high level during recent winter periods. Export capabilities of Germany and the Netherlands reveal a more or less constant trend.

Germany's export capabilities are subject to seasonal patterns and remain at a high level.

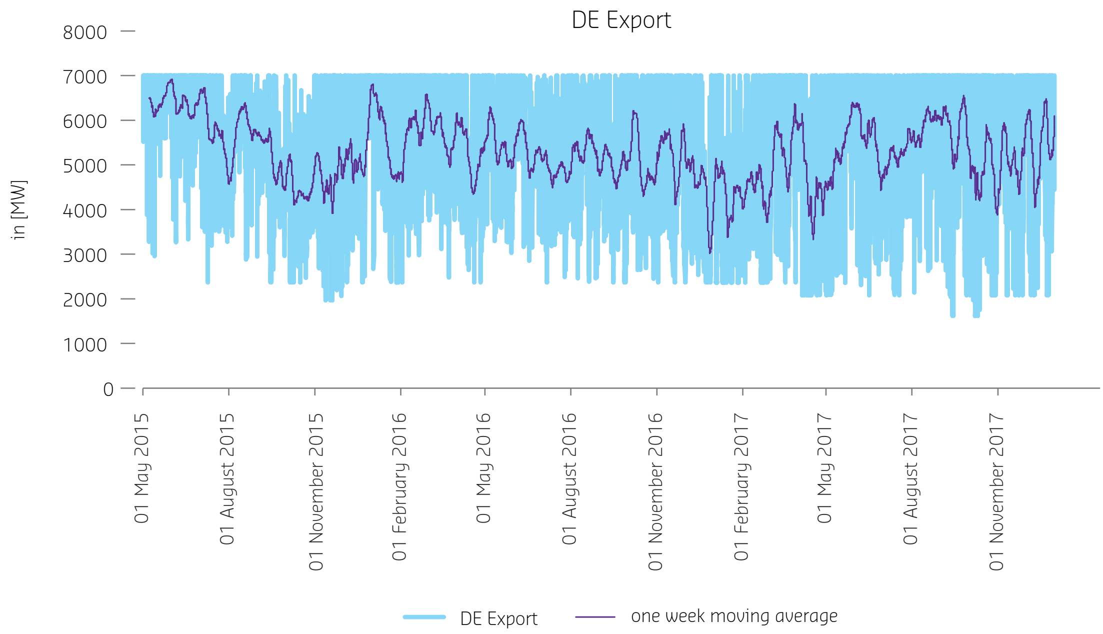


Figure 7: Maximum net position of Germany (Export) (Black line: moving weekly average)

[12] As the maximum and minimum net positions depend on the net positions of the other hubs they are not simultaneously feasible.

For **Belgium** the seasonal pattern reveals lower import capabilities during the summer periods. However, during winter periods with higher scarcities, in particular during the winter 2016/2017, import capabilities remained stable at a level of -4.5 GW.

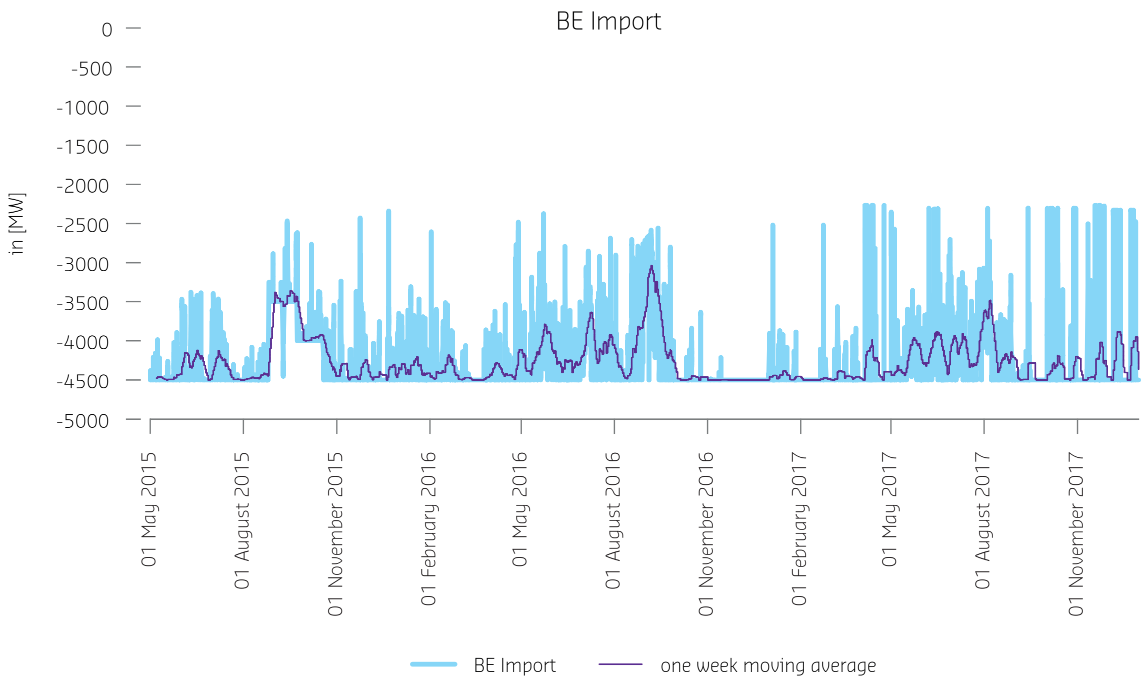


Figure 8: Minimum net position of Belgium (Import) (Purple line: moving weekly average)

For **the Netherlands** hours with low export capabilities increasingly occurred since end of 2016. This is in line with the development of active critical network elements located in the Netherlands as further detailed in the following section on the market situation.

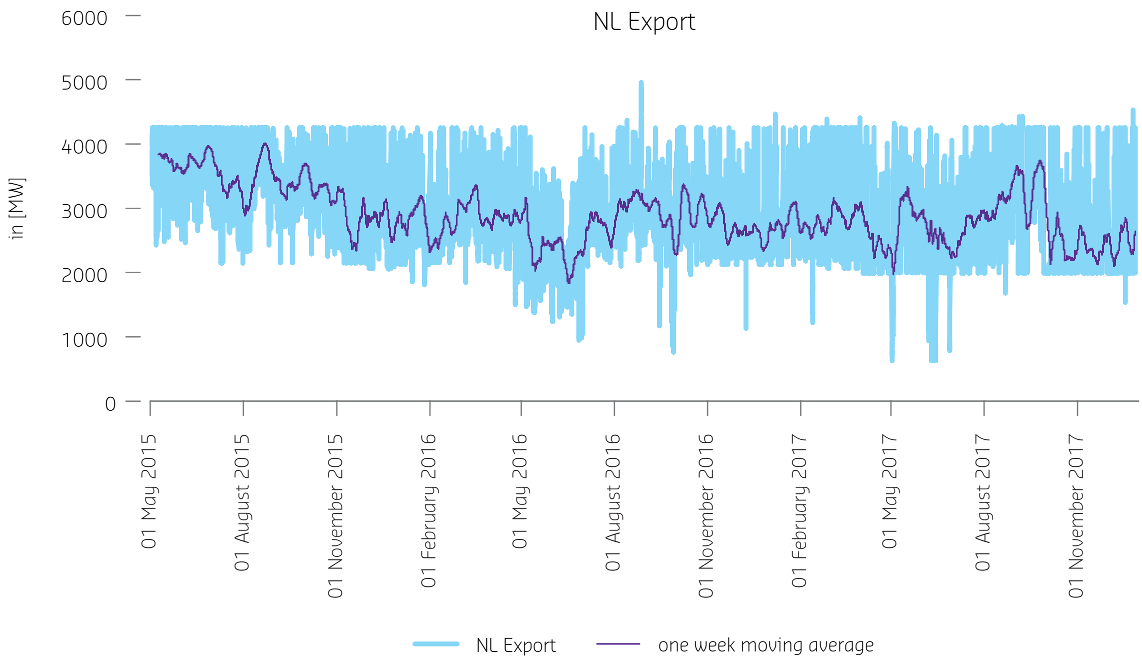


Figure 9: Maximum net position of the Netherlands (Export) (Purple line: moving weekly average)

For **France** the development of the minimum net positions (import) is quite volatile. In particular during the winter period minimum net positions exceeded -9.5 GW. Positive is the development in 2017, where import capabilities remained stable during the year and further increased towards winter months.

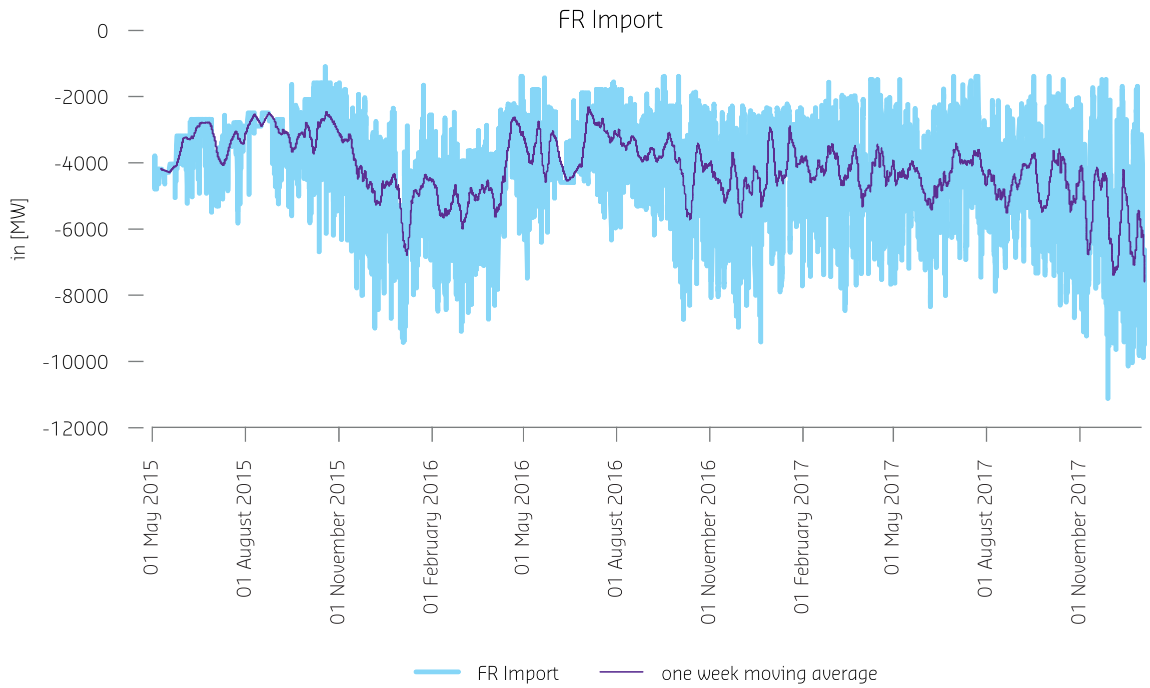


Figure 10: Minimum net position of France (Import) (Purple line: moving weekly average)

MAXIMUM BILATERAL EXCHANGES

The extracted maximum bilateral exchanges are subject to seasonal patterns. Driven by German wind infeed feasible bilateral exchanges from Germany to the Netherlands are lower during autumn periods. Maximum bilateral exchanges from Germany to France are usually higher during the winter period when electricity demand is at its highest (see winter 2015/2016 and 2017/2018).

For the winter period 2016/2017 however lower feasible bilateral exchanges from Germany to France are observed. It seems that measures taken by CWE TSOs to increase cross-border capacities have been overcompensated by the impacts of the significantly changed generation situation in CWE.

Maximum bilateral exchanges are calculated from the final flow based domain given to the market coupling. They indicate the maximum feasible exchanges between two bidding zones with the assumption that net positions of the other bidding zones are null. For instance, the maximum bilateral exchange between BE and FR is given by the maximum exchange feasible from BE to FR within the flow based domain, with net positions of NL and DE/AT/LU of 0 MW. Accordingly, maximum bilateral exchanges are not feasible simultaneously.

Monthly average maximum bilateral exchanges from Germany to the other CWE countries are subject to a dynamic development. In particular for possible exchanges to France Figure 11 reveals a seasonal pattern with lower maximum bilateral exchanges during the summer months. Interestingly maximum bilateral exchanges remained below 2015 levels during the winter period 2016/2017, despite measures taken by CWE TSOs to increase cross-border capacities, i.e. winter values. In contrast considerably higher maximum bilateral exchanges between Germany and France can be observed in Q4 2017. As outlined in section 2. on the capacity calculation inputs, besides technical parameters of critical network elements, the generation and load situation can be considered as a main driver of resulting cross-border exchange capabilities.

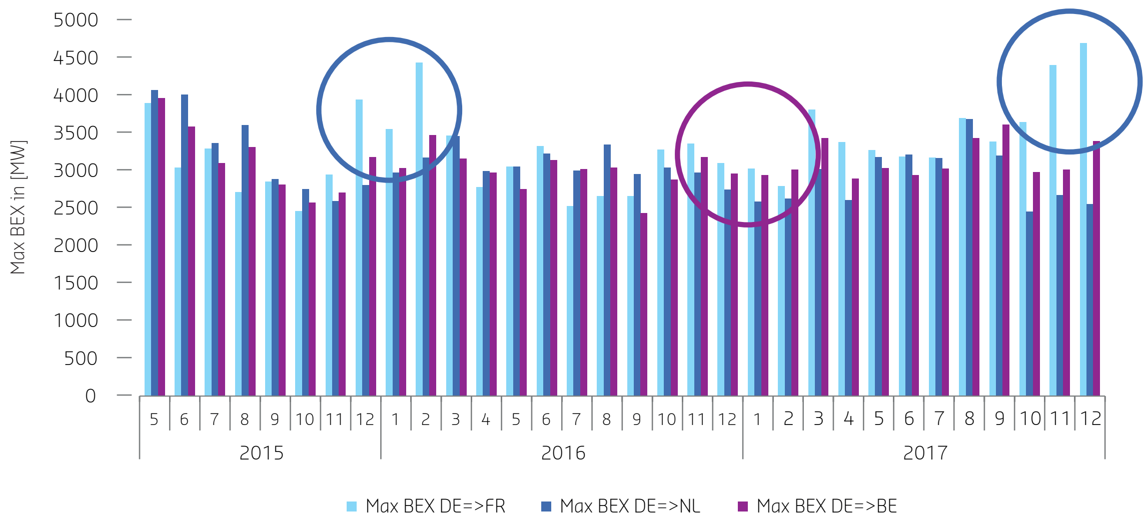


Figure 11: Monthly average of maximum bilateral exchanges (Max BEX) from Germany to CWE

4. Market Coupling and Capacity Allocation

The outputs of the flow based capacity calculation process are submitted to the market operators by TSOs. Subsequently the market coupling algorithm determines optimal market prices and net positions (importing or exporting) taking into account the flow based constraints. Transmission capacity between bidding zones is allocated in an implicit way and (bilateral) cross-border exchanges can be derived from the market results, i.e. net positions, and flow based parameters. One of the main targets of market coupling is the alignment of market prices between participating countries. In case of sufficient cross-border transmission capacities, electricity generation and demand can be regionally balanced leading to welfare gains. In this section we analyse the market situation by focusing on net positions, bilateral exchanges, market prices and active constraints.

INCREASING GERMAN DAY AHEAD NET POSITIONS

While for Germany, the Netherlands and Belgium the Day Ahead Net Positions increased over the last two years, for France lower Net Positions are observed, which is mainly caused by lower available generation capacity in France.

Net Positions for **Germany** reveal a slightly increasing trend of exports. In particular, during Q1 and Q2 of 2017 exports exceed historical levels, mainly as a result of measures introduced by Amprion and other CWE TSOs (i.e. winter values). Moreover, during Q2 and Q3 2017 higher Net Positions than in 2016 are found (see Figure 12).

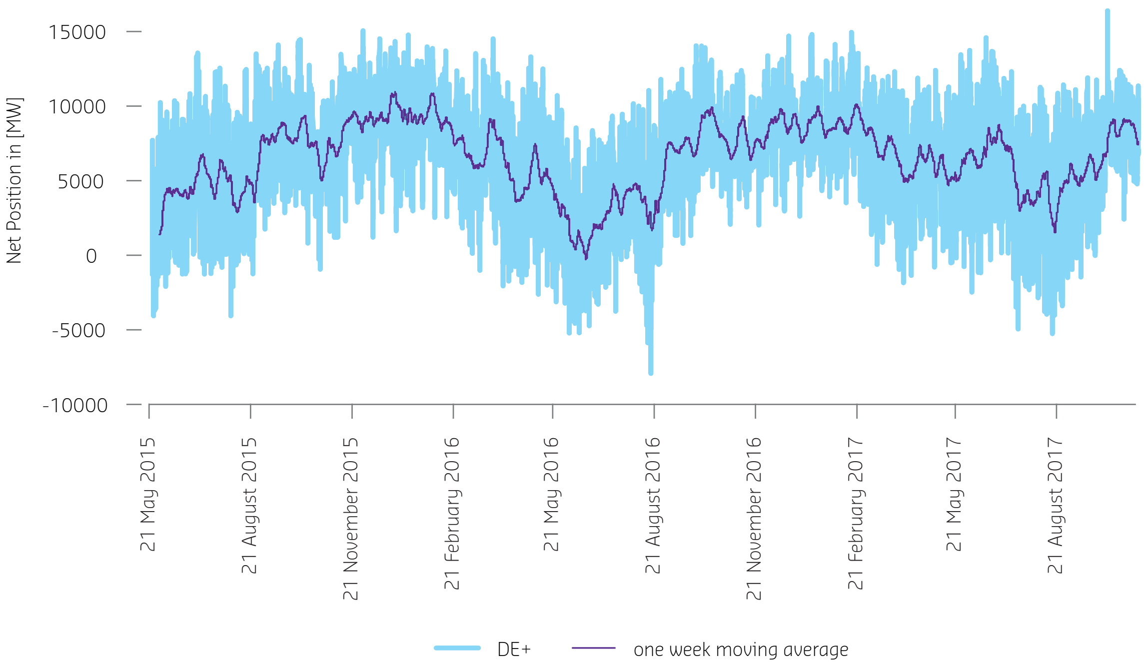


Figure 12: Net Positions for Germany (Purple line: moving weekly average)

For **Belgium** an increasing level of Net Positions is observed. However, Belgium remains a net importing country (see Figure 13).

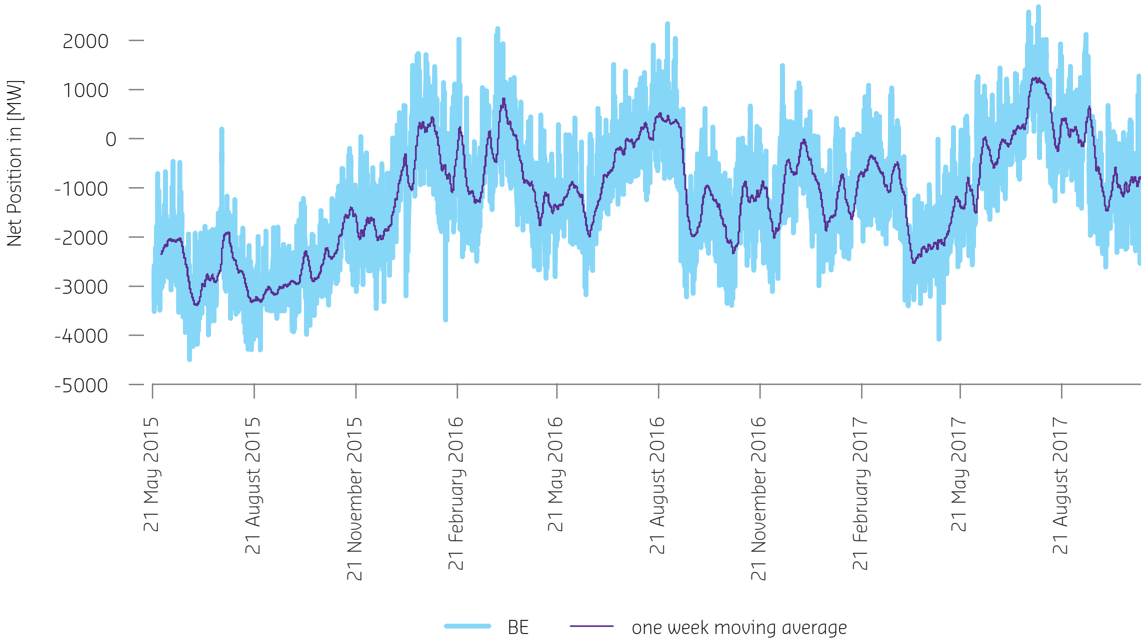


Figure 13: Net Positions for Belgium (Purple line: moving weekly average)

For **the Netherlands** also an increasing trend of Net Positions is found. In particular, during the winter period Net Positions increase, leading to considerable higher exports (see Figure 14).

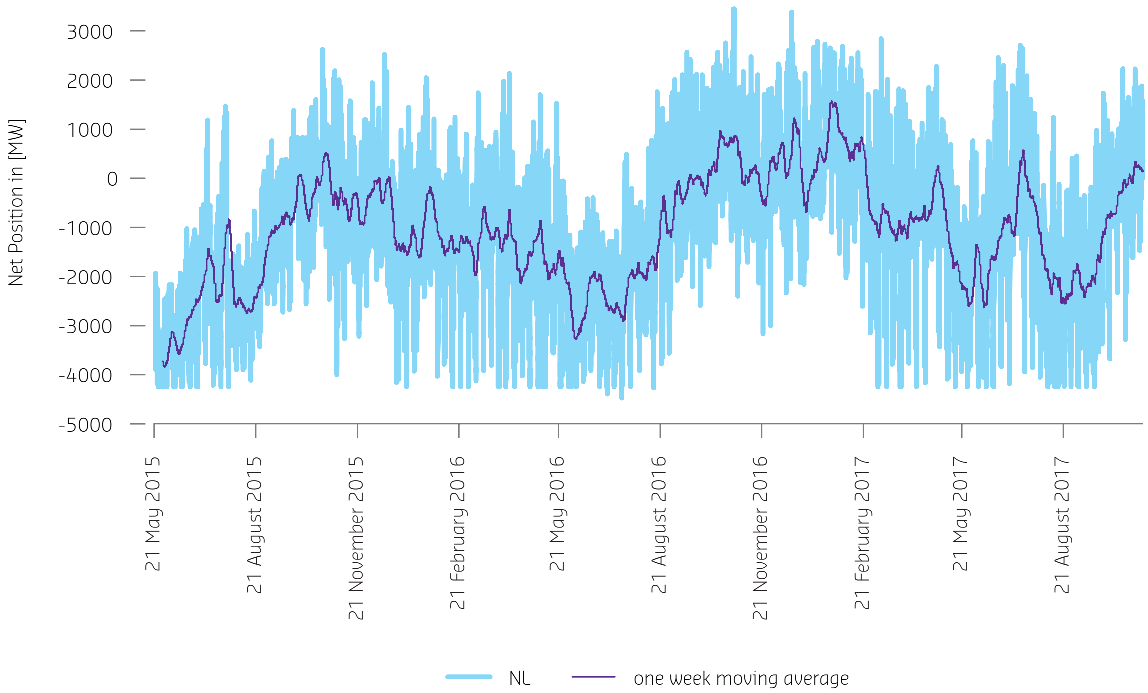


Figure 14: Net Positions for the Netherlands (Purple line: moving weekly average)

For **France**, however, an overall decreasing level of Net Positions is observed. While France was mainly exporting until Q2 2016, increased imports led to considerable lower Net Positions afterwards (see Figure 15).

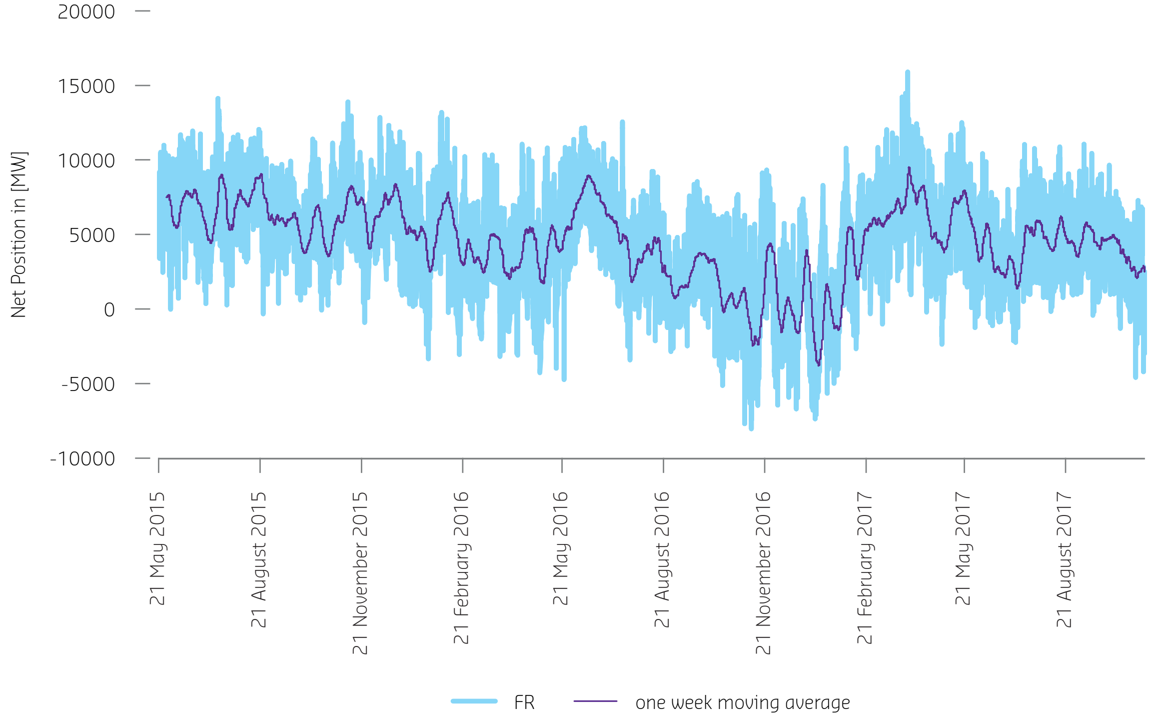


Figure 15: Net Positions for France (Purple line: moving weekly average)

BILATERAL DAY AHEAD EXCHANGES

In line with the development of Day Ahead Net Positions, Bilateral Day Ahead Exchanges from Germany to the CWE region remain at a high level. A shift of exports from northern CWE borders to southern borders can be observed. In particular imports of France from Germany and Belgium increase, which is mainly caused by more scarce generation capacity in France.

Apart from seasonal patterns the level of exchanges from Germany to the CWE region (DE to FR and NL) reveals no structural decrease (see Figure 16). While exports from Germany to the Netherlands decreased since 2015, exports to France increased, in particular during Q4 2016 and Q1 2017 (see Figure 17).

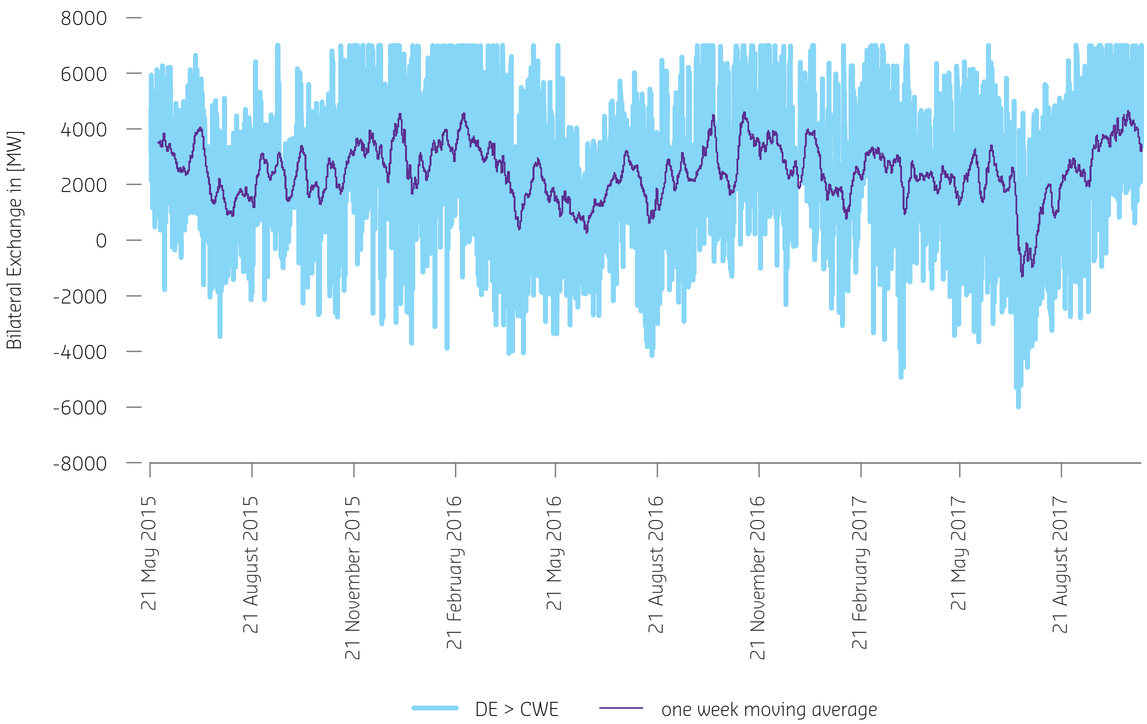


Figure 16: Exchange from Germany to CWE region (Purple line: moving weekly average)

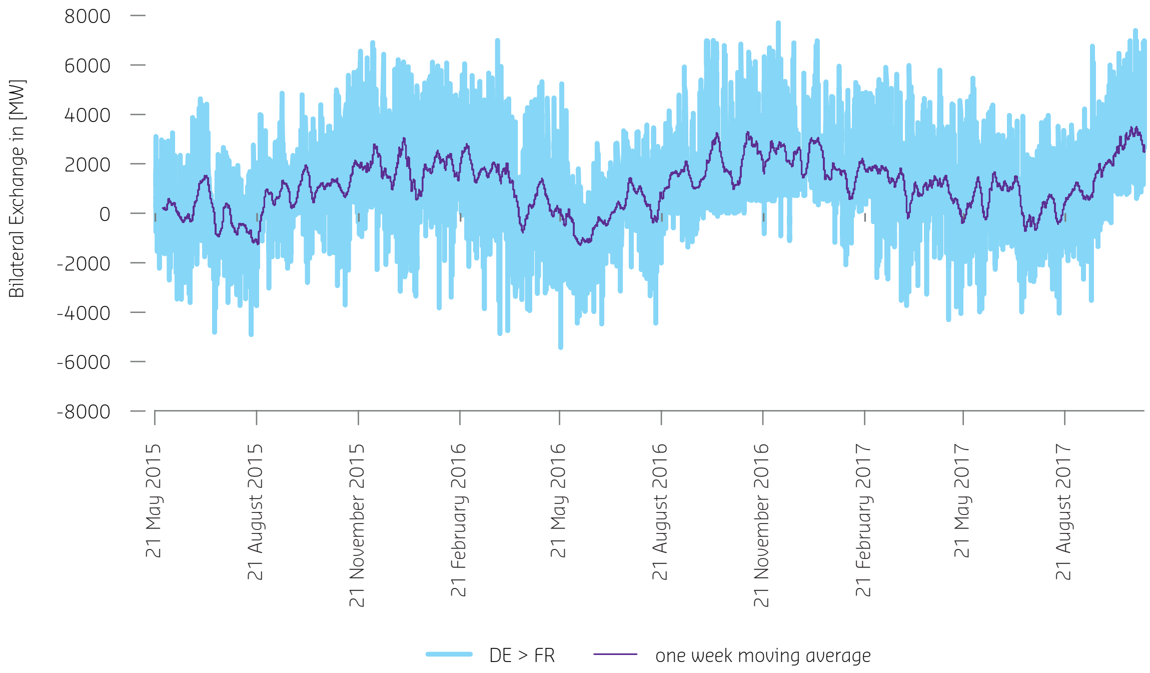


Figure 17: Exchange from Germany to France (Purple line: moving weekly average)

According to Figure 18 exports from France to Belgium decreased since 2015. In particular during the winter periods France is importing from Belgium, as from Germany.

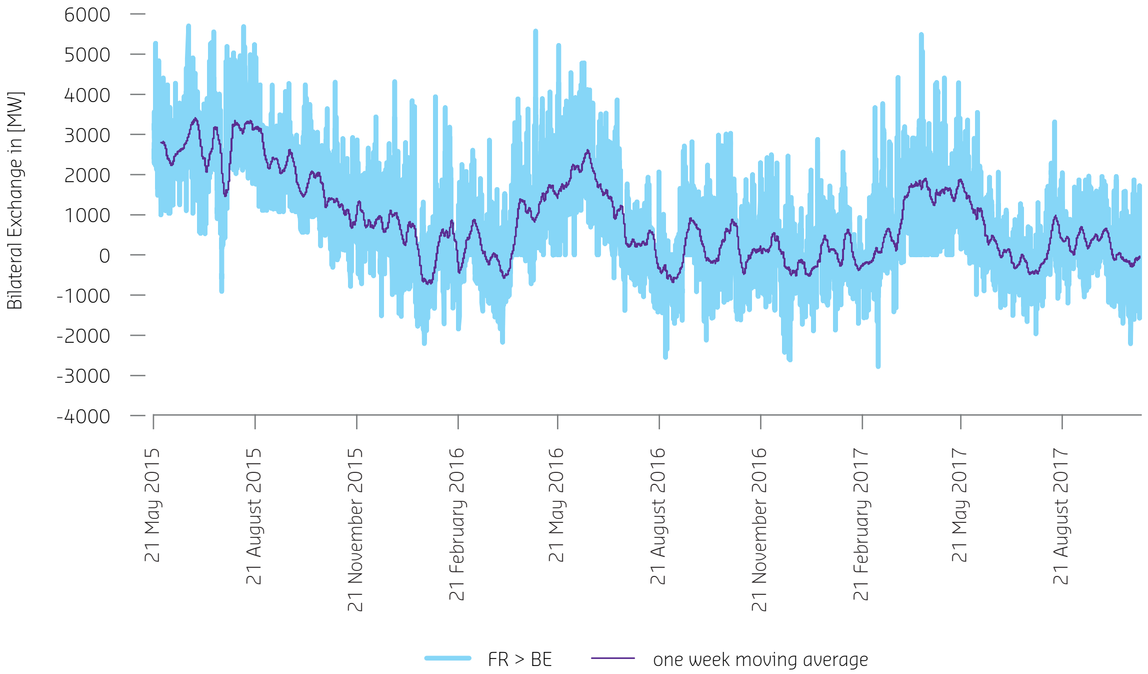


Figure 18: Exchange from France to Belgium (Black line: moving weekly average)

Figure 19 reveals a considerable shift of exports from northern CWE borders to southern borders (sum of exchanges: NL → DE + NL → BE + BE → FR + DE → FR) over the past two years. In particular during the winter periods higher exchanges from northern CWE countries to southern countries can be observed.

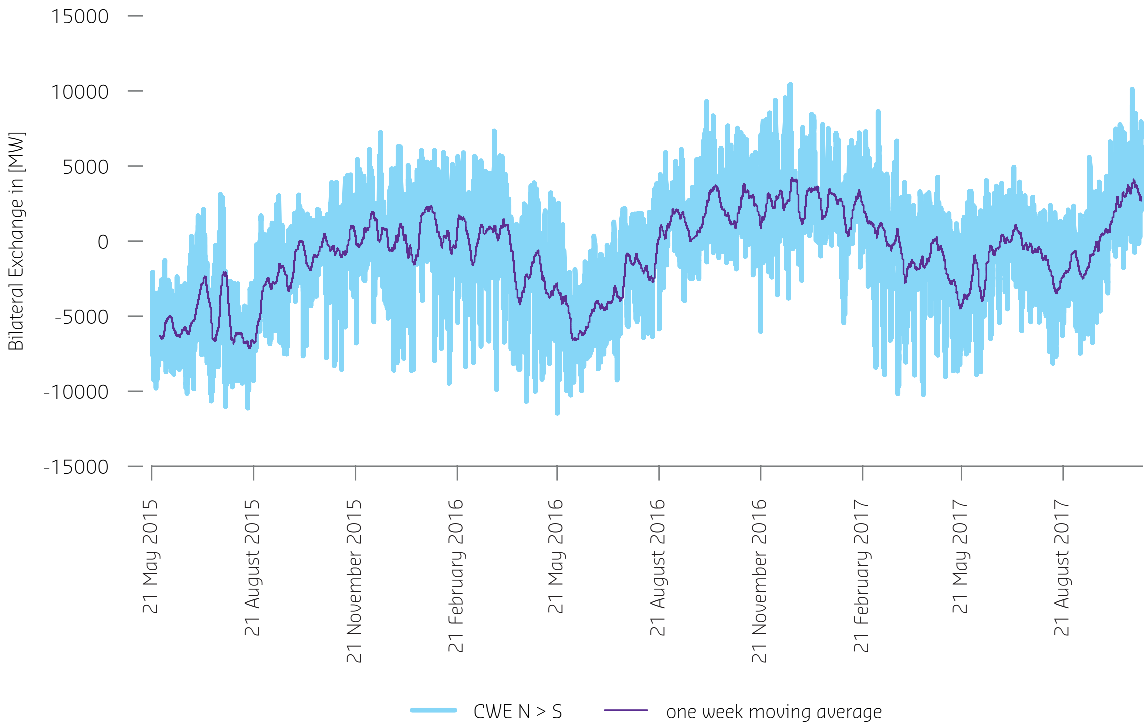


Figure 19: Exchanges from CWE North to South (Purple line: moving weekly average)

INCREASING TREND OF PRICE CONVERGENCE

One of the main targets of market coupling is the alignment of market prices between participating countries. Sufficient cross-border transmission capacities are crucial for the achievement of the so-called price convergence. Over the past years a steady increase of hours with a full price convergence (price differences = 0) between CWE countries can be observed. Accordingly, CWE TSOs make a significant contribution to a cost-efficient balancing of supply and demand across the CWE region.

In the case of sufficient cross-border exchange capacities, no price differences between CWE countries occur. If commercial exchanges are limited by active transmission constraints, prices between CWE countries diverge. Accordingly, the price convergence is an indicator for the level of market integration in the CWE region.

As Figure 20 shows, the level of market integration increased over the past years. Lower levels of price convergence are however observed during the winter periods with high electricity demand and stressed grid situations. The lower price convergence during the winter period 2016/17 is moreover driven by the stressed supply situation in CWE countries. Nevertheless, an increasing trend can be observed.

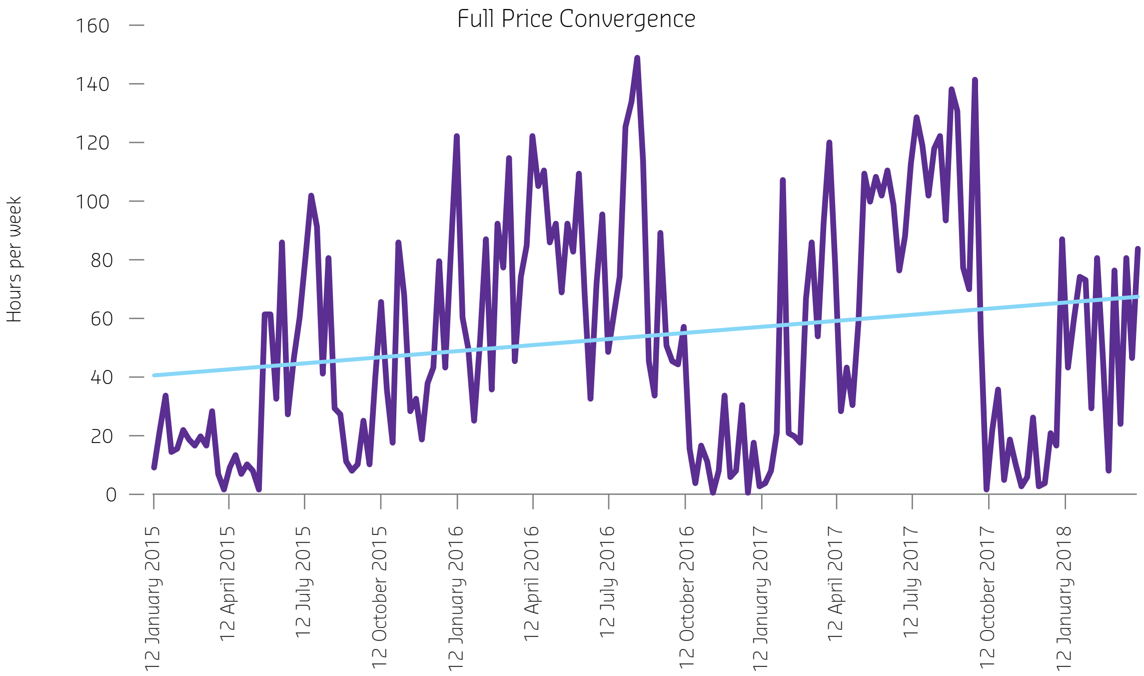


Figure 20: Hours per week with full price convergence (price spreads between CWE countries = 0)

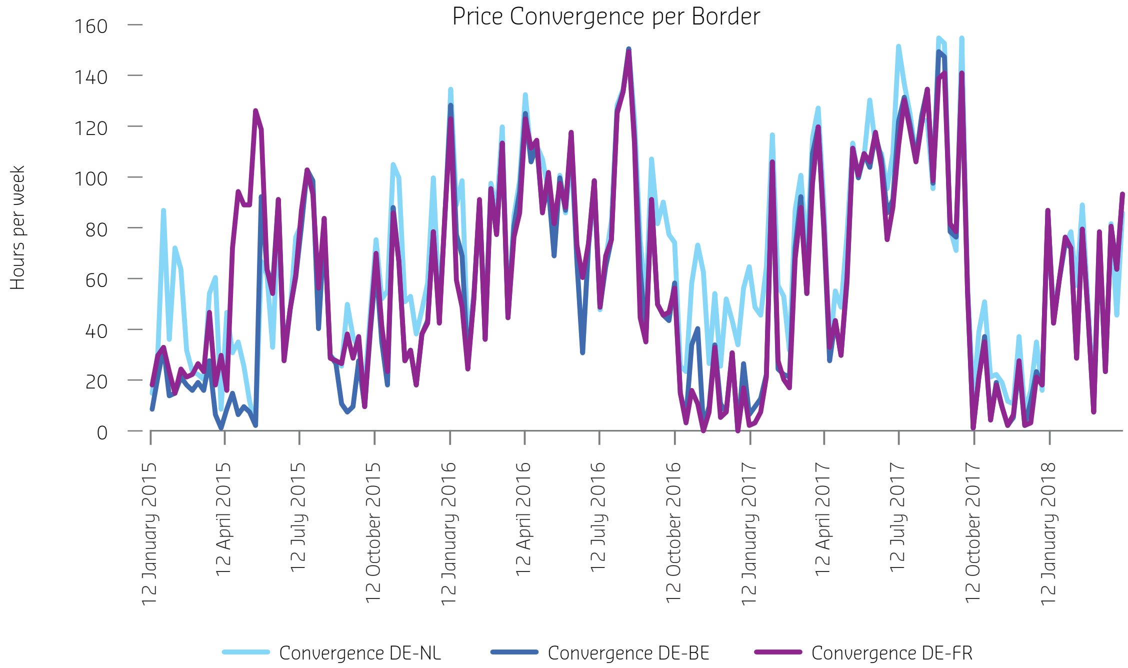


Figure 21: Hours per week with price convergence per border (price spread between respective countries = 0)

FREQUENCY OF ACTIVE CONSTRAINTS

The frequency of active constraints is subject to seasonal effects and driven by generation and load patterns in CWE countries. Improvements like the introduction of winter values and dynamic line rating on Amprion CBs has reduced the frequency of Amprion's active CBs significantly.

The development of active CBs was subject to dynamic changes over the past two years (see Figure 22). While in the beginning mainly cross-zonal CBs limited cross-zonal trade, from November 2015 on also internal CBs actively limited cross-border exchanges. Limiting cross-zonal elements are mainly located at the German-Dutch and Dutch-Belgian borders. Main active internal elements are located close to the German-Dutch border in the Amprion control zone (see gray area).

In particular during the winter periods with high North-South flows internal elements become relevant, whereby the introduction of winter values on Amprion CBs in November 2016 led to a considerable reduction of the frequency. Also a shift to internal elements in the Netherlands and Belgium can be monitored (see purple and blue areas). Moreover, cross-zonal elements at the German-Dutch border were limiting more often in the beginning of 2017 (see crosshatched areas).

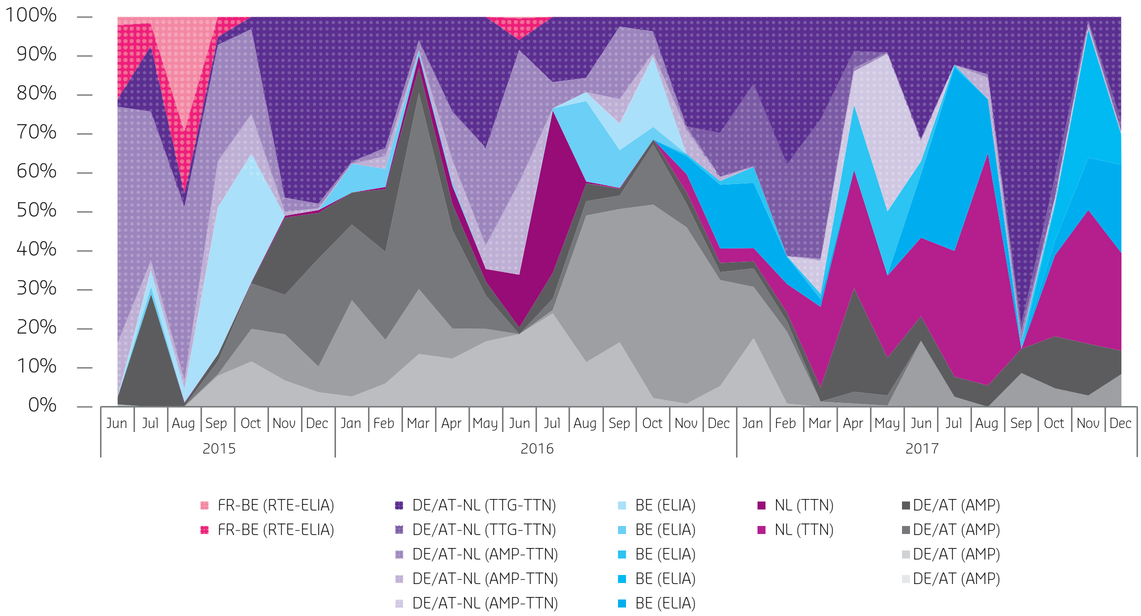


Figure 22: Relative frequency of top 10 active CBs

MEASURES TAKEN BY AMPRION

After the go live of the CWE FBMC in 2015 mainly tie-lines between Amprion and the Netherlands were constraining cross-border exchanges. Due to the central location of the Amprion control zone in the CWE region, these and other critical network elements play a major role for exchanges between CWE countries (see frequency of active constraints in particular in 2016).

Removal of Final Adjustment Values

In order support the market coupling, Amprion focused as a first step on decreasing the number of tie-lines constraining the day-ahead market. This could be achieved by stepwise decreasing the amount of FAV on exactly these tie-lines and by consequently monitoring the real time behavior of the grid. Accordingly, Amprion decreased the Final Adjustment Value (FAV) by 50 MW on a monthly basis. This process has been finalized for the business day 13.01.2017. From this day on no positive FAV (positive FAV is decreasing the remaining available margin) for Amprion constraints has been applied anymore.

Introduction of winter limits and dynamic line rating

With regard to the internal critical network elements, Amprion has introduced beginning with business day 30.11.2016 the so called winter limits. This led to an increase of the thermal capacity of up to 20 % for each of the most constraining lines. In addition Amprion has implemented dynamic line rating on the most relevant lines as of 27.09.2017.

Impact of the introduced measures

The development in 2017 reveals that other constraints than the ones of Amprion are now most constraining the market and the measures taken by Amprion can be considered as very beneficial for the CWE market coupling.

It is Amprion's persistent aim is to maintain a high level of cross-border exchange capacities, while guaranteeing system security at the same time. On top of efforts made to improve the market coupling in recent years there are further improvements expected for the near future.

Further Development of the Dynamic Line Rating

Amprion is currently taking the next step in the application of dynamic line rating in the capacity calculation. Within this second step Amprion is going to move away from the four categories of temperature depending line rating towards the Cigre Curve[13]. Also the temperature forecast of 14 weather stations will be used and linked to the lines nearby.

New interconnector between Amprion and the Netherlands

In the course of summer 2018 a new double-circuit 380kV line between Germany and the Netherlands will be commissioned. This will lead to additional exchange possibilities on that border and facilitate cross-border trading in the CWE region.

13) The Cigre Curve is based on the thermal balance between the gained and lost heat in the conductor due to the load and environmental conditions. Variables that are considered are the ambient temperature, solar radiation, wind speed, wind direction and the current of the conductor.

Figure 23 shows the frequency of active CBs for each hour of the day from 06.2015 – 08.2017. Accordingly internal elements become relevant during morning and evening hours, mainly driven by generation and load pattern.

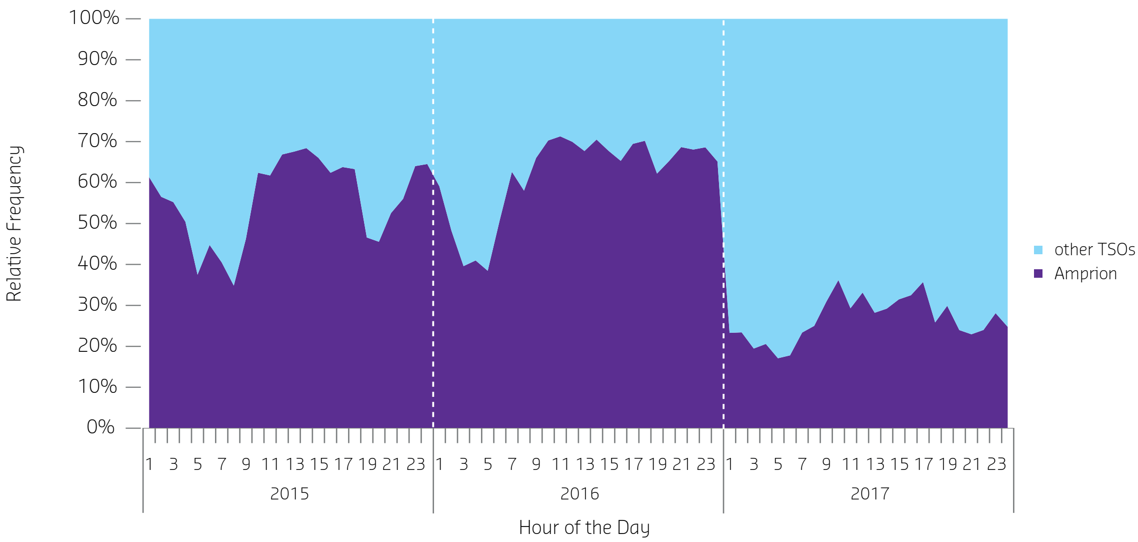


Figure 23: Relative frequency of top 10 active CBs per hour of the day from 06.2015 – 11.2017

In particular evening hours (18h and 19h) are characterized by a higher electrical demand and economic value of cross-border exchanges. In this context it has to be noted that the frequency of internal Amprion elements limiting cross-border exchanges during evening hours decreased by more than 60 % in 2017 against 2016. According to Figure 23 corresponding decrease can be observed also for the other hours of the day.

An analysis of the correlations between limiting internal Amprion CBs and resulting Flow Based Net Positions gives further insights in the interactions between commercial constraints and market results. The correlations in the following table can be interpreted as indicated in the first row:

	NEG. CORRELATION: HIGHER RAM ON ACTIVE INTERNAL AMPRION CBS CORRELATES WITH HIGHER IMPORT OF BE	POS. CORRELATION: HIGHER RAM ON ACTIVE INTERNAL AMPRION CBS CORRELATES WITH HIGHER EXPORT OF DE	NEG. CORRELATION: HIGHER RAM ON ACTIVE INTERNAL AMPRION CBS CORRELATES WITH HIGHER IMPORT OF FR	NEG. CORRELATION: HIGHER RAM ON ACTIVE INTERNAL AMPRION CBS CORRELATES WITH HIGHER IMPORT OF NL
	BE	DE / AT	FR	NL
Okt 16	0,056	0,699	-0,543	-0,355
Nov 16	-0,372	0,558	-0,385	-0,188
Dec 16	-0,174	0,625	-0,416	-0,156
Jan 17	-0,277	0,790	-0,381	-0,491
Feb 17	0,235	0,487	-0,363	-0,423
Mrch 17	0,416	-0,174	0,348	-0,503
Apr 17	-0,018	0,256	0,146	-0,314
May 17	0,555	0,019	0,384	-0,859
Jun 17	0,016	0,312	0,295	-0,730
Jul 17	0,088	-0,455	0,556	-0,219
Aug 17	-0,657	0,092	0,188	-0,140
Sep 17	0,055	0,475	-0,131	-0,566

The correlation analysis reveals that higher RAMs on active internal Amprion CBs correlate with higher Net Positions of Germany and higher imports of France, whereby the relation is more pronounced during the winter period. In contrast, the correlation between active internal Amprion CBs and export of the Netherlands is high. The found relationships are in line with the commercial exchanges shown before. However, it should be noted that correlations coefficients are below 0,5 in most months, meaning that Net Positions of CWE countries can be only partly explained by active internal Amprion CBs[14].

This applies even more to the correlations between RAMs on active internal Amprion CBs and Net Positions of Belgium, where no clear relation can be identified. This is in line with the findings in Figure 22, where mainly internal Dutch CBs and cross-zonal CBs between Germany, the Netherlands and Belgium are binding in the considered time period.

[14] A correlation coefficient of 0.5 means that 25 % (R2=0.52) of the variability of the time series of the Net Positions can be explained by the variability of the time series of RAM on Amprion CBs. Under all considered cases computed correlation coefficients are significant at a 1 % significance level.

LOWER IMPACT OF AMPRION'S ACTIVE CBS ON PRICES

The relation between active CBs and price spreads is based on economic principles, which imply that marginal costs (shadow prices) increase with an increasing level of scarcity. Accordingly, it is found that with decreasing RAMs price spreads between CWE countries increase. There is a correlation between Amprion CBs and price spreads between DE-FR, DE-BE and DE-NL, which however decreased over time. Consequently, price spreads in CWE are increasingly determined by other constraints, mainly in the Netherlands and Belgium.

The level of price differences between market zones indicates the scarcity of transmission capacity between the respective zones. Accordingly, with lower transmission capacities (RAM) scarcity and corresponding price spreads increase. From the previous analysis it should be clear that the CWE region is characterized by a North-South transit. Consequently, critical branches affected by this North-South transit determine the price spreads (also referred to as congestion costs).
In the following the relation between active critical branches of each CWE TSO and the price spreads between DE-FR, DE-BE and DE-NL are analyzed.

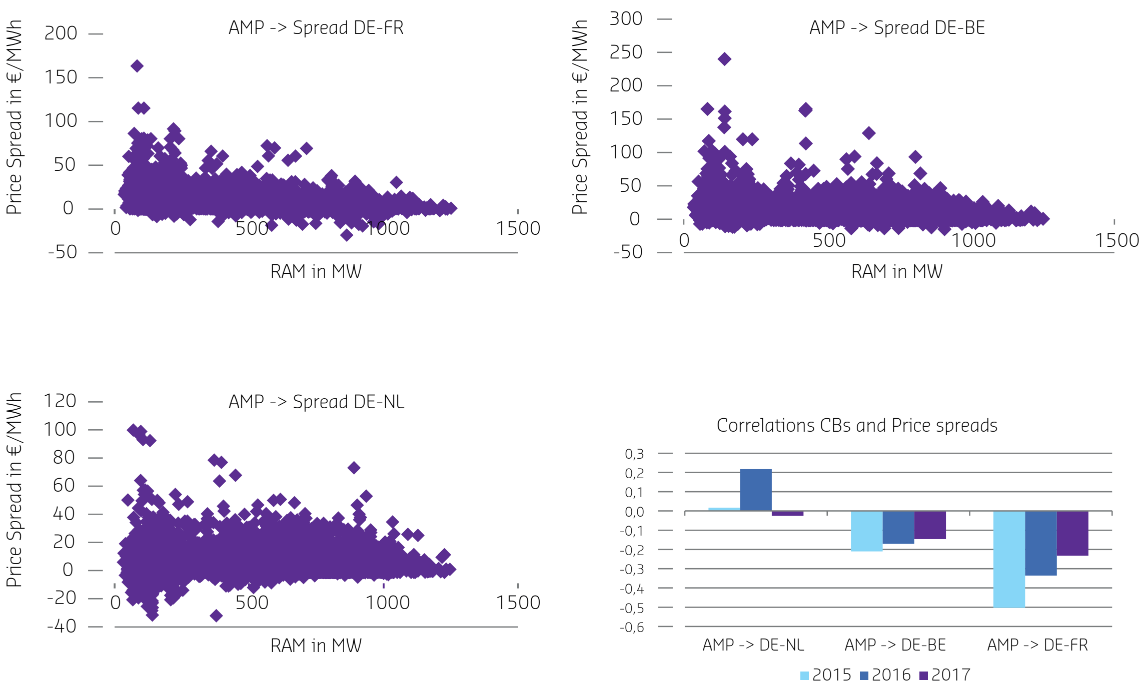


Figure 24: Impact of AMP CBs on Price Spreads 06.2015-08.2017 (without price spike on 14 November 2016)

For Amprion CBs it is found that with decreasing RAMs price spreads between Germany and other CWE countries increase. This is confirmed by the corresponding correlations of -0,38 for DE-FR and -0,15 for DE-BE[15].

However, it should be noted that the correlation between active Amprion CBs and price spreads has decreased between 2015 and 2017 (from -0,50 to -0,23 for DE-FR and from -0,21 to -0,15 for DE-BE), meaning that increasingly also other active constraints are determining the price spreads. Moreover, it should be noted that when considering only internal Amprion CBs the correlations are even smaller: -0,17 for DE-FR and -0,12 for DE-BE. In particular for price spreads between Germany and France, a considerably lower correlation is found.

For the other CWE TSOs comparable relations between active CBs and price spreads are found, i.e. increasing price spreads with decreasing RAMs on CBs. As mentioned before for Amprion CBs the correlation between RAMs and price spreads between Germany and France was reduced from 2015 to 2017. This result corresponds to an increasing negative correlation between active CBs of Elia and price spreads between France and Germany (from -0,07 to -0,17), meaning that exchanges between Germany and France are increasingly limited by Belgian network elements. As shown in the next section this is however not driven by loop flows, which decreased over the past months.

LOOP FLOWS

Loop flows are part of any zonal market design and occur when physical exchanges deviate from commercial schedules. Despite an increasing level of wind infeed in DE, for loop flows via BE a decreasing trend can be observed.

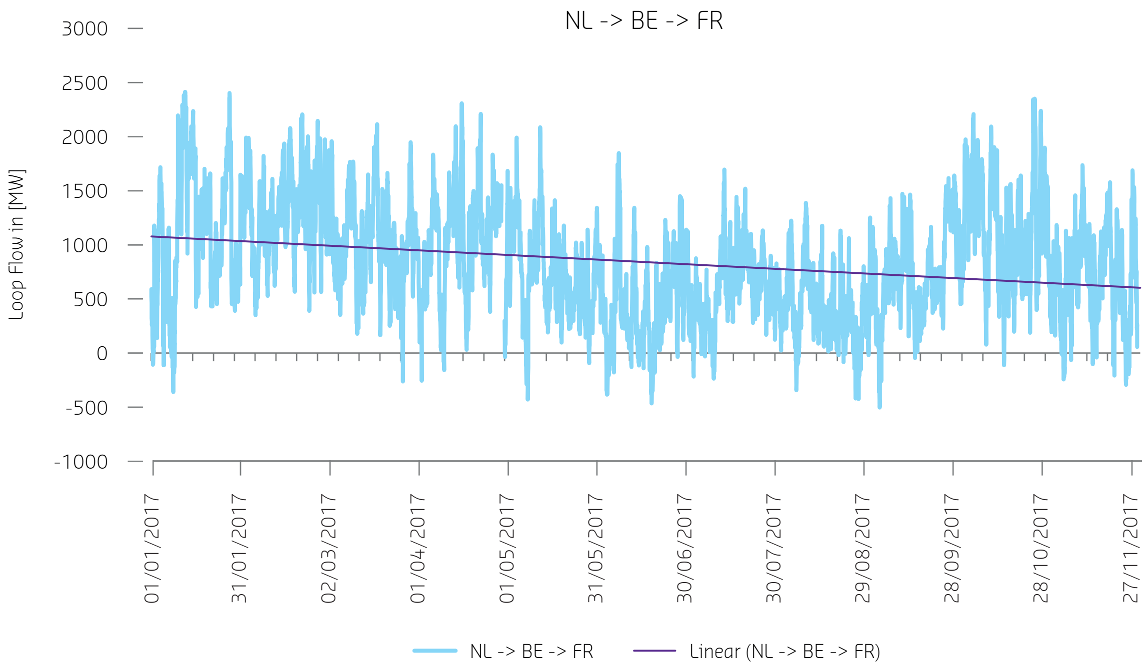


Figure 25: Loop flows via BE (Elia website)

15) A negative correlation means a negative relationship between RAMs and price spreads. Accordingly, when RAMs decrease price spreads increase..

5. Grid Operation

The market coupling results are submitted to the TSOs and subsequently translated into physical flows during real-time grid operation on the basis of schedules nominated by market participants. In case of deviations between commercial exchanges and physical flows TSOs apply remedial actions, i.e. redispatching measures, in order to maintain secure grid operation.

In this section we focus on the grid situation by analyzing physical exchanges between CWE countries and redispatch volumes of German TSOs.

PHYSICAL EXCHANGES

Physical flows between CWE countries are in line with commercial exchanges. For France increasing imports are found, which is in line with decreasing net positions found in section 4. Consequently, higher export flows from Belgium and Germany to France and corresponding higher transits from North to South are observed.

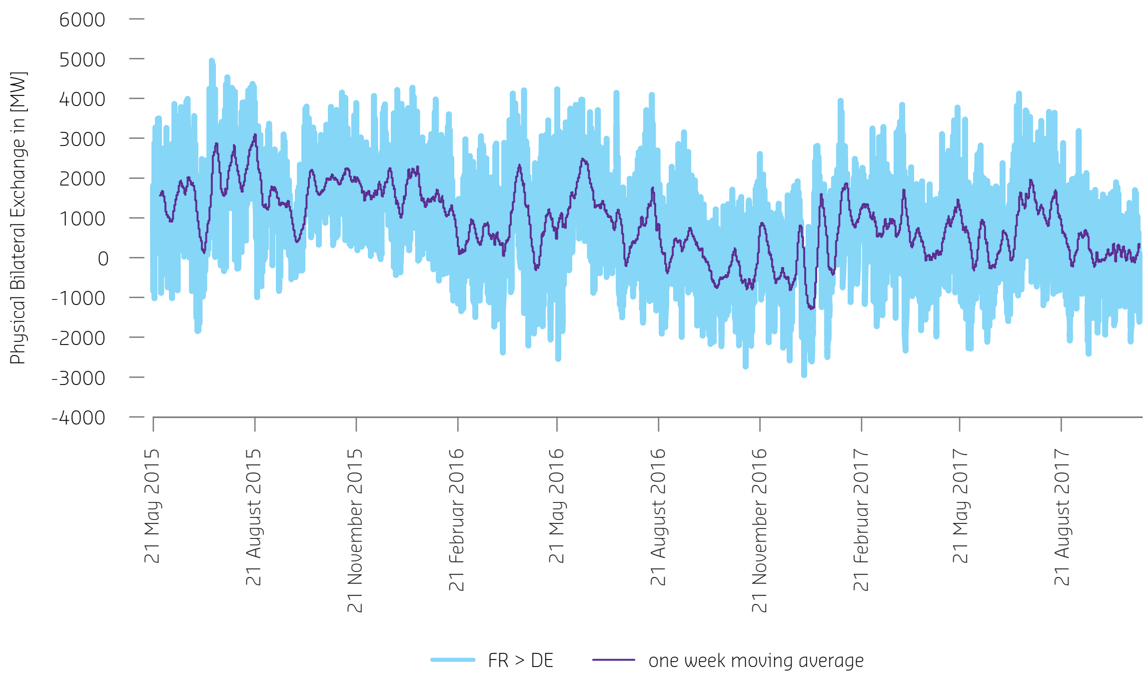


Figure 26: Bilateral Physical Exchange from France to Germany (Black line: moving weekly average)

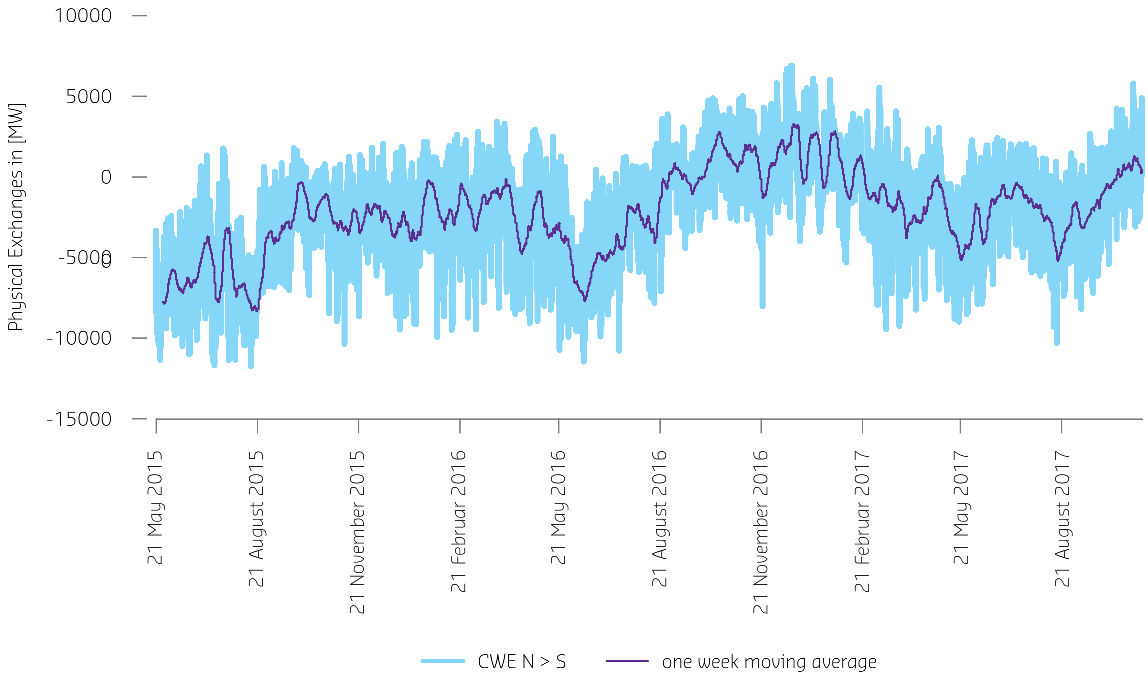


Figure 27: Physical Exchanges from CWE North to South (Black line: moving weekly average)

High export flows from Germany are to a large extent supported by firm generation capacity and corresponding physical exports from the Amprion control zone. During the winter period 2016/17 net exports of Amprion exceeded 12 GW representing nearly 70 % of the maximum vertical load of the Amprion control zone. At the same time imports of southern control zones reached 15 GW.

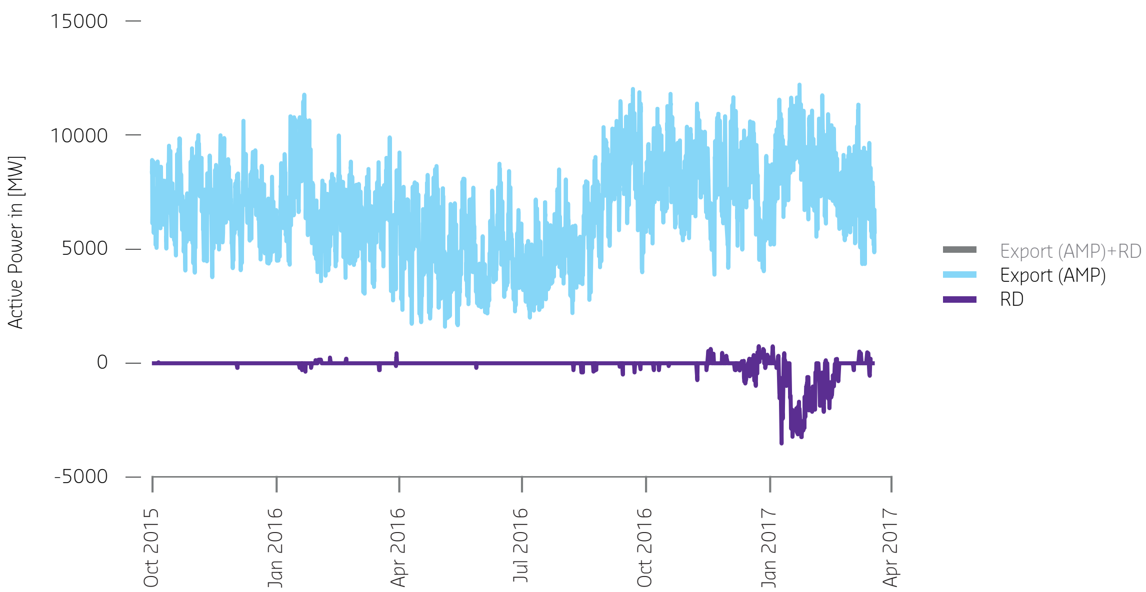


Figure 28: Physical Exports from Amprion to neighbouring control zones and activated Redispatch

REDISPATCH VOLUMES

The increase of North-South transits in the CWE region led to considerably higher redispatch volumes in particular during the winter period 2016/17. For Amprion the redispatch volumes reached a historical height, showing our strong commitment to the European market integration and the support we provide to our neighbors despite incurring significant costs.

During the winter period 2016/2017 German TSOs faced a historical situation with considerable redispatch needs in combination with low availability of generation capacities and low redispatch potential. There had never been before such critical situations with up to 92 redispatch measures per day.

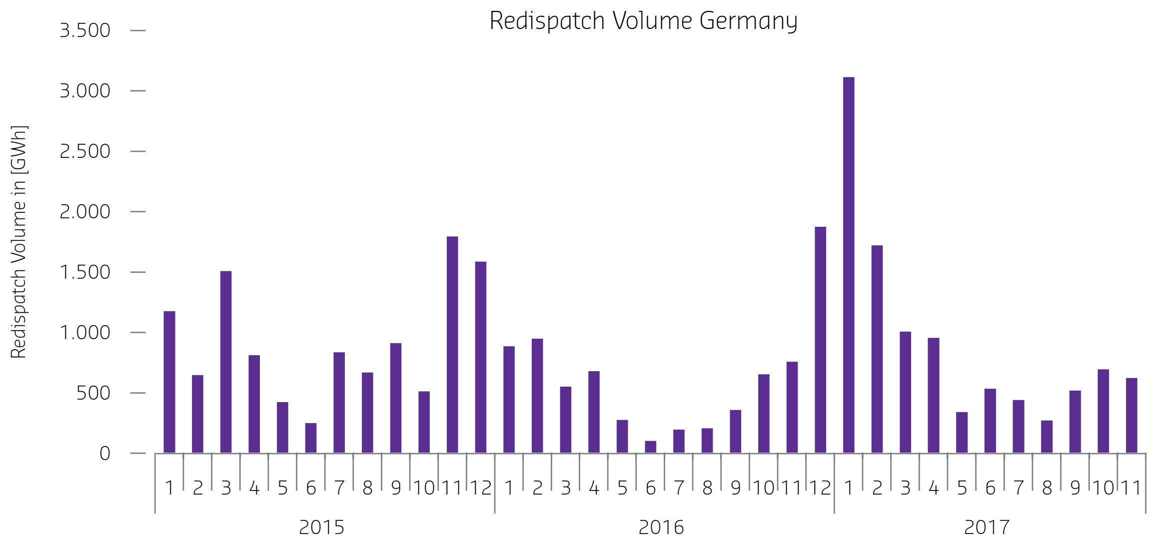


Figure 29: Total monthly redispatch volumes Germany

Figure 30 shows the redispatch volumes per TSO. It can be seen that all German TSOs face higher redispatch needs during winter periods when the North-South transit occurred.

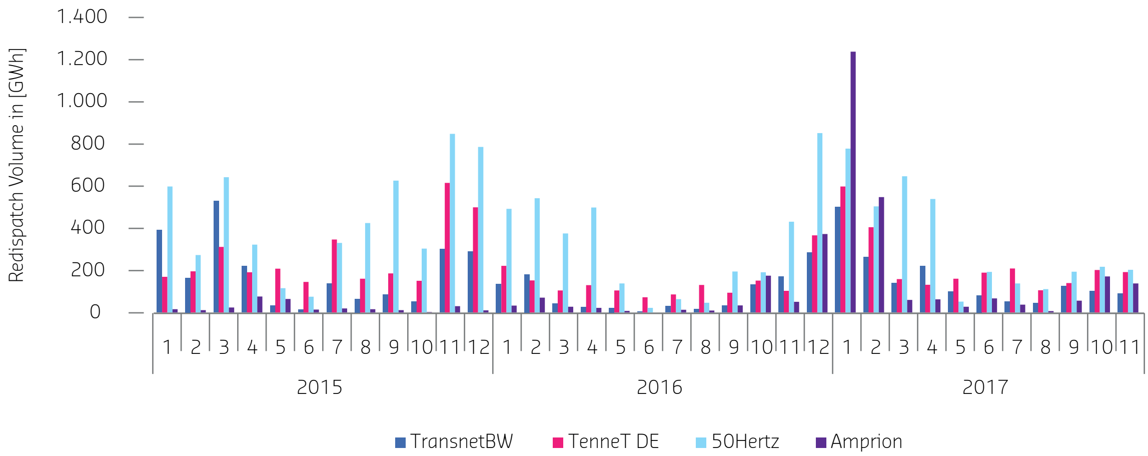


Figure 30: Monthly redispatch volumes per TSO

Redispatch volumes for TenneT DE and 50Hertz can be explained mainly by the German wind infeed, i.e. weekly correlation between redispatch and wind generation: >0.35.
In contrast, the extreme high redispatch volumes of Amprion observed during the winter period 2016/17 represent an outlier. A correlation analysis reveals that redispatching measures in the Amprion control zone are rather correlated with the load and supply situation in southern CWE countries than with the German wind infeed, i.e. weekly correlation between redispatch in Amprion control zone and 1. wind generation: 0.04; 2. load and supply situation in France: 0.49.

The number of redispatch measures per day indicates the occurrence of critical grid situations, where TSOs had to intervene in real-time operation. Thereby it has to be noted that redispatch measures are coordinated in a manual way today. Consequently, in case of an increasing number of redispatch measures the risk of errors increases.

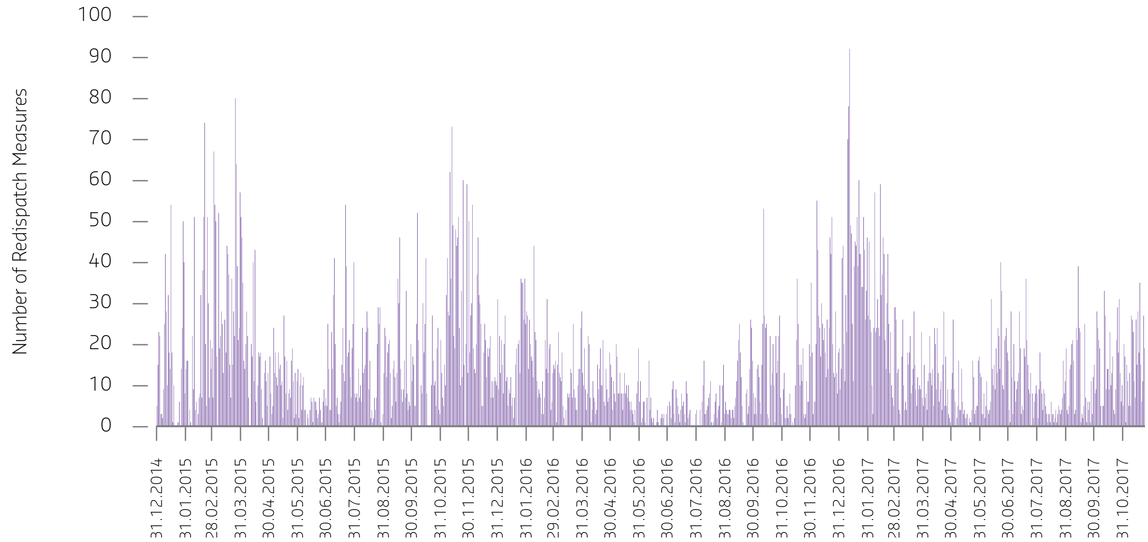


Figure 31: Number of Redispatch Measures per Day for German

References

The analysis in this document is based on data taken from:

- NRA combined monthly reports
- Entso-E Transparency Platform
- Elia website (Loop flows)
- netztransparenz.de (Redispatch)

Wohland et. al (2018): "Natural wind variability triggered drop in German redispatch volume and costs from 2015 to 2016." Available at: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0190707

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